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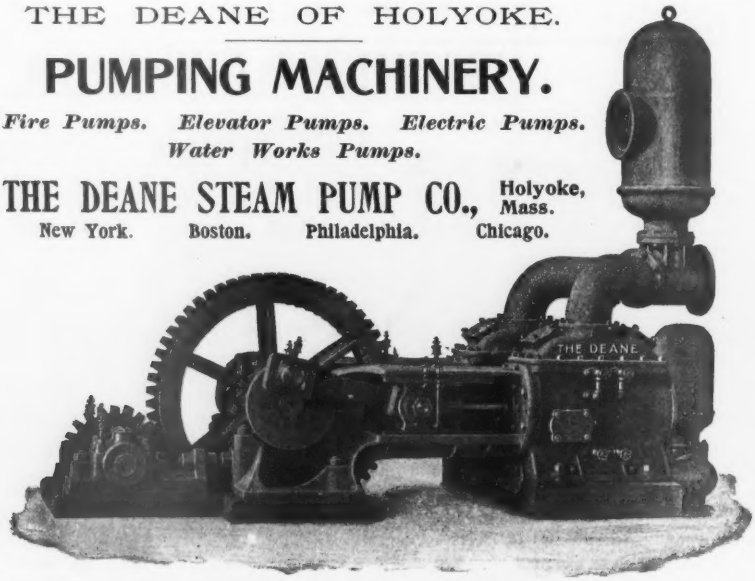

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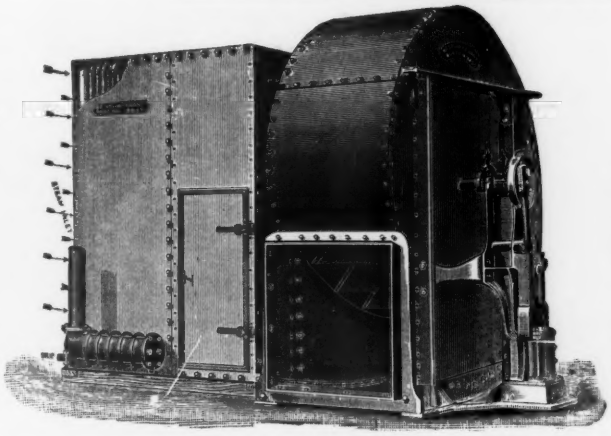

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THE TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

EDITED BY

ROBERT P. BIGELOW, Ph. D.,

Secretary of the Society.

THE TECHNOLOGY QUARTERLY is an illustrated magazine published by the MASSACHUSETTS INSTITUTE OF TECHNOLOGY. It is devoted to original articles upon various subjects in **Architecture, Civil Engineering, Mechanical Engineering, Electrical Engineering, Physics, Chemistry, Biology, Bacteriology, Mining** and **Metallurgy,** or, in general, the **Sciences** and their applications to the **Useful Arts.** Attention is called to two especially notable features of the QUARTERLY, viz.: *The Results of Tests made in the Engineering Laboratories* and *The Review of American Chemical Research.*

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TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

VOL. XI. MARCH, 1898. NO. 1.

PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-SIXTH YEAR, 1897–98.

THE meeting of the SOCIETY OF ARTS which should have been held October 14 was omitted to allow members to attend a Memorial Meeting[1] held in Music Hall, under the auspices of the Corporation and the Faculty, in honor of the late President Francis Amasa Walker.

The meeting was called to order at 8 P.M. by Augustus Lowell, Esq., of the Corporation, who introduced His Excellency Governor Roger Wolcott as the presiding officer. The Governor upon taking the chair made a short but forceful address, and then introduced the principal speaker of the evening, Honorable George F. Hoar, United States Senator from Massachusetts. Senator Hoar delivered an oration, in which he spoke eloquently of the life and character of President Walker, and praised his achievements as a soldier, an administrator, and a scholar.

Invitations to this meeting had been sent to all members of the SOCIETY OF ARTS.

[1] For a complete report of the proceedings of this meeting, see Massachusetts Institute of Technology, Meetings Held in Commemoration of the Life and Services of Francis Amasa Walker. Boston, 1897. 39 pp. Portrait. 8°.

THURSDAY, October 28, 1897.

The 502d meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M.

The meeting was called to order by Mr. George W. Blodgett, Chairman of the Executive Committee, who announced that at a special meeting of the Corporation, held October 20, Professor James M. Crafts had been elected President of the Institute. President Crafts was then introduced, and took the chair.

The record of the previous meeting was read and approved. The Secretary announced the death of Mr. Thomas Doane, a distinguished engineer and friend of education, who in May had been elected a member of the Executive Committee of the SOCIETY OF ARTS. By unanimous consent the President was authorized to appoint the committee of five required to nominate a candidate to fill the vacancy in the Executive Committee.

The following were duly elected Associate Members of the Society: Messrs. George W. Bryden, of Portland, Maine; Orrin S. Doolittle, of Reading, Pennsylvania; W. H. Jaques, of Little Boar's Head, New Hampshire; Jesse F. Johnson, of Montreal, Canada; Marshall O. Leighton, of Montclair, New Jersey; George H. Norman, of Newport, Rhode Island; William T. Hall, of Boston; Walter E. Piper, of Fells, Massachusetts; J. C. Hobart, of Cincinnati, Ohio; and James H. Hutchings, of Boston.

In introducing the speaker, the President referred to the great difficulty of obtaining exact measures of heat, and described the methods employed at the International Bureau for the comparison of thermometers. Mr. Charles L. Norton then presented a paper on "Recent Work in Heat Measurement at the Institute," and began with a description of the apparatus used here for the comparison of thermometers. It contains an inner box, open at both ends. This is inclosed in an outer box provided with three propeller shafts, each bearing twelve propellers with blades bent so that when the inner box is in place the circulation is in a steady stream around and then through the inner box. There is a heating coil at one end. The whole box is lined with cork, which was found to be the best non-conductor. Between the box and its lining there is a layer of asbestos, with fine wires, forming an electric heater by which loss of heat is prevented. The apparatus may be kept at a constant temperature to within 0.005° C. for an hour.

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An apparatus for testing the conductivity of steam pipe coverings was described next. This consists of an electric heater immersed in oil, with a stirrer in a section of pipe around which the substance to be tested is placed. Methods for determining the heat of combustion were then considered. Two kinds of apparatus are used in the Institute. A new form of bomb, suggested by Professor Holman, is made of aluminum bronze, and consists of two nearly hemispherical halves, with a nut to join them in the center. The manipulation is simplified by the shape, and the accuracy is about $\frac{1}{2}$ per cent. Equally good results are obtained by the apparatus for burning coal in a stream of oxygen, which consists of a combustion chamber, a cooling chamber, and a cooling coil. The coal is placed on a shelf in a platinum crucible with a perforated cover.

For measuring high temperatures the common thermo-electric pyrometer is employed. In determining the melting points of metals absolute control is secured by using an electric heater instead of a Bunsen flame. The paper was illustrated by an exhibition of apparatus and by lantern views.

While thanking Mr. Norton, the President pointed out that this work is of great value to the school, in that it makes it possible to place in the hands of the students instruments of precision possessing a degree of accuracy seldom found even in laboratories devoted entirely to research.

The Secretary announced that an amendment to the By-Laws would be brought up at the next meeting. The Society then adjourned.

THURSDAY, November 11, 1897.

On this day the 503d meeting of the SOCIETY OF ARTS was held at the Institute at 8 P.M., with Mr. Blodgett in the chair.

The record of the previous meeting was read and approved. There being no other business, the Chairman introduced Mr. Louis J. Hirt, of Brookline, who read a paper on "Cable and Underground Electric Roads." The paper dealt especially with the duplex system employed on the New York cable roads. In this system there are two cables, either of which may be used alone, or both of them may be used at once. The central station was described first, special attention being paid to the tension carriage for regulating the cable. Then

views of cross sections of the duplex road were shown, exhibiting the details of construction, Provision is made for a signal system, consisting of electric bells and telephones, by means of which inspectors and conductors may communicate with the central station. The details of construction of grips, switches, curves, and the automatic gypsy used for keeping the cable in place at depressed curves, were described at length. Attention was then directed to underground electric conduits. The cost of running a road of this kind is one and one-half cents a car-mile higher than with the trolley. The method of operation and the plow used on the Lexington Avenue line were described, this being taken as the highest type of the underground electric road. A complete metallic circuit is used. The cost of construction of an underground electric road is one-third that of a cable road. The road with an underground conduit was declared to be the coming form of street railway. The paper was illustrated by a large number of lantern views. The Chairman thanked the speaker for his valuable contribution, and then the Society adjourned.

THURSDAY, December 9, 1897.

The 504th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., President Crafts in the chair. The record of the previous meeting was read and approved. Messrs. Arthur T. Hopkins, of Somerville, L. Frederic Howard, of Boston, and Professor Joseph J. Skinner, of the Institute, were duly elected Associate Members of the Society.

The following resolution, which, after having been approved by the corporation, had been presented in writing at a previous meeting, was adopted by unanimous vote of the Society:

Resolved, That the By-Laws of the SOCIETY OF ARTS be amended by striking out the word *four* in the last sentence of Section II (Duties of the Executive Committee), and by inserting in its place the word *three*, so that the sentence shall read, "Three members shall constitute a quorum for the transaction of business."

In introducing the speakers of the evening the President called attention to the improvement in the product and advantage, both to producer and consumer, that has resulted from the development of the canning industry. Mr. S. C. Prescott was the first speaker, pre-

senting a paper written with Mr. W. Lyman Underwood, entitled "Contributions to Our Knowledge of the Micro-organisms and Sterilizing Processes in the Canning Industries," which dealt chiefly with the means employed to prevent the souring of corn.[1] He said the first attempt to pack corn was made by Isaac Winslow, of Maine, in 1839. His first attempt to employ steam sterilization was a failure, and retorts did not come into general use until 1879. Cookers were introduced in 1890, and enabled packers to do away with the preliminary boiling of the cans. The losses due to sour corn and the means of detecting this condition were discussed in full. Souring is always due to the action of bacteria, six species having been found in sour corn. Intermittent sterilization is impracticable on a commercial scale, and retorts properly used will kill all bacteria in twenty minutes at a temperature of 120° C. Mr. Underwood followed with an exhibition of lantern slides, illustrating the machinery employed in packing corn and the bacteria which are found in sour corn.

The paper was discussed by several speakers. Professor Sedgwick criticised a report published by the Canadian Government, in which intermittent sterilization was advocated. The President thanked the speakers, after which the Society adjourned.

ROBERT PAYNE BIGELOW, *Secretary.*

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[1] The paper is published in full on pp. 6–30 of this journal.

CONTRIBUTIONS TO OUR KNOWLEDGE OF MICRO-ORGANISMS AND STERILIZING PROCESSES IN THE CANNING INDUSTRIES.

II. The Souring of Canned Sweet Corn.

By S. C. PRESCOTT and W. LYMAN UNDERWOOD.[1]

Read December 9, 1897.

In a paper read before the Society of Arts in October, 1896,[2] we showed the extent of the canning industry in this country, and the importance to it of accurate knowledge of the bacteriological principles of sterilization. In that paper we dealt with the packing of clams and lobsters, and described some of the bacteria which are active in the deterioration of these products in case sterilization is not complete. It is interesting to notice that some of the results which we published at that time have since been confirmed by a specialist employed by the Canadian Government[3] to investigate the discoloration of canned lobsters.

We now desire to give an account of our more recent investigations in another branch of the industry, namely, the packing of sweet corn. This art constitutes a very large industry, as is shown by the fact that in 1895 seventy-two million 2-pound cans (72 thousand tons) were packed in the United States.

Historical.

The growth of the art has been rapid, for it was not until about 1853 that corn was packed at all with success. Maine has been generally acknowledged as the home of corn packing, and its claim to be so considered is probably just. In 1839 Isaac Winslow began experiments in canning corn at or near Portland. He was for a long time unsuccessful. He first attempted to cook the ears

[1] Mr. Prescott is Instructor in Biology, Massachusetts Institute of Technology, and Mr. Underwood is of the William Underwood Co., Boston.

[2] Technology Quarterly, Vol. X, No. 1, March, 1897, pages 183–199.

[3] Canadian Department of Marine and Fisheries, 29th Annual Report, Supplement No. 2, Ottawa, 1897.

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of corn whole, but this proved unsatisfactory on account of their bulk, and it was also thought that the cobs absorbed the sweetness. He next tried to remove the kernels whole by means of a fork, but this was soon abandoned, and the corn was afterward cut from the cob. His first experiments were made in a common household wash boiler, and in a very limited way. Small quantities were treated by various methods, but nearly all the corn spoiled. Some kept, however, and gave promise of ultimate success. In 1843 he built a small copper steam boiler of about two barrels capacity, and carrying ten or twelve pounds of steam. To this he connected wooden tanks lined with zinc and made steam tight. In these crude retorts he "processed" the corn, subjecting it to the direct action of live steam. Nearly the whole lot spoiled, and in consequence of this failure, steam apparatus was abandoned. The next year he returned to open boilers, and continued his experiments with varying success for ten years. In 1853 he applied for a patent, but this was not allowed until 1862.

An abstract from the patent may be of interest: "After a great variety of experiments I have overcome the difficulties of preserving Indian corn in the green state without drying the same, thus retaining the milk and other juices, and the full flavor of fresh green corn until the latter is desired for use. Instead of a hard, insipid, or otherwise unpalatable article, I have finally succeeded in producing an entirely satisfactory article of manufacture, in which my invention consists. I have employed several methods of treatment. My first success was obtained by the following process: The kernels being removed from the cob were immediately packed in cans, and the latter hermetically sealed so as to prevent escape of the natural aroma of the corn, or the evaporation of the milk or other juices of the same. Then I submitted the sealed cans and their contents to boiling or steam heat for about four hours. In this way the milk and other juices of the corn are coagulated as far as may be, boiling thus preventing the putrefaction of these most easily destructible constituents. At the same time the milk is not washed away or diluted, as would be more or less the case if the kernels were mixed with water and then boiled. By this method of cooking green corn the ends of the cans are bulged out, as though putrefaction and the escape of the resultant gases had commenced within the cans. Consequently strong cans are required.

"I recommend the following method: Select a superior quality of the green corn in the green state, and remove the kernels from the

cob by means of a curved or gauged knife or other suitable means. Then pack these kernels in cans and hermetically seal the latter so as to prevent the evaporation under heat or the escape of the aroma of the corn. Now expose these cans of corn to steam or boiling heat for about one hour and a half, and then puncture the cans and immediately seal the same while hot, and continue to heat for about two and one-half hours longer. Afterwards the can may be slowly cooled in a room at a temperature of 70° to 100° F."

For nearly twenty years this method was in use, the only change being that the time of processing was somewhat shortened. About 1879 retorts were introduced in corn packing, and the second heating was done in them, the time being reduced from two and one-half hours to one hour. The advent of cookers about 1890 did away with the first heating in the water bath, so that now this is abandoned as an agency of sterilization. Many of the processes formerly carried on by hand are now carried on by machinery. Maine leads in the packing of sweet corn, but large quantities are packed in New York and Maryland and in the West, particularly in Iowa, Illinois, and Michigan.

The Souring of Canned Sweet Corn.

Sweet corn, when properly prepared, is one of the most valuable of all canned foods, as it retains much of its original flavor, is popular, and is sold at a price within the reach of all. If, however, the sterilizing has not been done thoroughly, there may result fermentations caused by bacteria which have not been killed, producing what is known as "sour" corn. It is not definitely known when sour corn first appeared. In the experiments of Isaac Winslow, spoiling of some kind resulted, but so far as we have been able to ascertain, its nature has never been described. In a Massachusetts factory, however, where corn has been packed with success for nearly twenty years, souring suddenly occurred in 1878. Maine was also somewhat affected at the same period. Until this time corn had been processed for five hours at a boiling temperature with no loss, but in the year just mentioned, with exactly the same treatment, this manufacturer experienced a total loss. Some of this corn was sent to chemists for analysis with the hope that a remedy might be found at once. It was reported by them to be due to "fungus consisting of little globules that boiling heat did not dissolve."

Early in the following year (1879) the Massachusetts packer who owned the factory referred to attempted to continue with the old process, but the corn spoiled. Retorts were procured, and with their higher heat satisfactory results were obtained. For sixteen successive years he experimented with the old process with the intention of returning to it if possible. The corn so packed and kept at a temperature of 90 to 100° F. invariably spoiled, swelling on the third or fourth day. It was thought that the trouble might be local, and to decide this he visited distant sections, carefully selected and gathered corn, and, returning at once to his factory, packed it in the old way with the least possible delay, working sometimes all night that this might be done. The results were always the same — the corn could not be successfully packed by the old method. Had any locality been found where this could have been done, he intended removing his factory to that neighborhood.

The exact chemical changes which take place when sour corn is produced are difficult to state, and vary under different conditions. The sugar and starch in the corn are fermented for the most part to lactic, acetic, and butyric acids, thus giving rise to the souring. There are also other products of decomposition. Gases are frequently evolved, but being dissolved by the liquid in the can at the ordinary temperature, in the majority of cases no swelling results.

The loss resulting from sour corn during the last eight or ten years has been enormous, in some years being much more than in others. Thousands of dollars have been lost in a single year by individual manufacturers who have experienced this trouble. Moreover, the uncertainty and the possibility that losses may be incurred are constant sources of worry and uneasiness to those engaged in this industry.

Detection of Spoiled Cans.

Spoiling in canned goods is generally indicated by bulging of the ends of the cans, caused by the pressure of the gases produced within. Thus a packer may generally detect any unsoundness before the goods are put upon the market, as all are overhauled and inspected before ultimate shipment. In the case of sour corn, however, at least in its first stages of deterioration, there is no outward indication of trouble. It is only under rather exceptional conditions that swelling occurs. If

the temperature and other conditions are favorable for the rapid development of germs which can produce fermentation with the formation of gas, swelling will result. Since, however, the latter conditions rarely prevail in the factories, the detection of sour corn becomes difficult. Corn which is sweet when shipped may become sour many months afterward. To illustrate this fact an instance may be cited where from the same day's packing two lots of corn were shipped, one to the northern and one to the southern part of the United States. That which was sent to the North was in perfect condition at the end of a year, while that which went to the warmer climate became sour in a short time. Many instances of the same nature have been noticed by different packers, and similar results may be obtained by laboratory experiments. The explanation of this fact probably is that all the bacteria were not killed by the heating to which these cans were subjected, and that the conditions for growth of the micro-organisms became favorable only in the warmer locality. Provided sterilization is not complete, there seems little reason to doubt that climatic condition is a most important factor in the souring of corn. It should always be borne in mind that if processing or sterilization is complete sour corn cannot result, because the germs of fermentation are destroyed. When souring occurs the percentage of bad cans may be small, but often runs from 10 to 40 per cent., or even higher. Such goods are generally returned, and an attempt is made to separate the sweet from the sour cans. To do this there are two methods in common use.

According to the first method, the cans are put into a tank of water at a temperature of 80° F., where they stand for from six to twelve hours in order that the contents may be heated uniformly throughout. They are then removed and their ends just submerged in water at 190° F. Here they remain for not more than thirteen minutes. At the end of that time those cans which are swelled are rejected as sour. The other method is to boil the cans for one hour. This causes all the ends to bulge. They are then cooled, and those whose ends remain bulged for more than eight hours are rejected, while those which "snap back" within this time are considered satisfactory. Both these methods depend for their success upon the fact that at certain temperatures gas is produced rapidly by bacteria within the cans.

Bacteriology of Sour Corn.

Our investigations commenced in February, 1897, with the examination of a large number of cans of sour corn. On opening the cans no change was noticeable to the eye, the corn appearing fresh and of a natural color. In some cases a sour odor could be detected, but in others this was not observed. It was to the taste that the trouble was most apparent, the corn being sour and of a peculiar astringent quality. Bacteriological examination showed sound cans to be sterile, while spoiled cans invariably gave evidence of bacterial action. Pure cultures of twelve species of bacteria were obtained, of which eleven were bacilli, and one was a micrococcus. It must not be supposed that these bacteria are disease-producing; they probably act merely upon the saccharine and starchy matter, transforming it to organic acids and other substances of more or less disagreeable taste and odor, and so make the corn unpalatable and destroy its commercial value.

By inoculating sterile cans of corn with these organisms we have been able to produce souring in all respects similar to that of the spoiled cans from which they were originally taken. Our experiments were conducted in the laboratory in the following manner: A number of cans were selected and all of them were punctured, this operation being done in a sterile glass chamber. A part of the cans were inoculated with cultures obtained from sour corn, and all the cans were then sealed and put in an incubator kept at the blood heat. The cans which had been inoculated commenced to swell in from twelve to twenty-four hours, while those not inoculated remained as sound as when put in the incubator. Thus we easily proved that a vacuum is not necessary for keeping canned corn, and that air may be admitted to a sound can and spoiling will not result, provided proper precautions are taken that the air so admitted be free from germs. This statement will undoubtedly be regarded with incredulity in some quarters, so strong is the popular belief among packers in the indispensability of a vacuum, yet a long line of experiments from the days of Tyndall to the present time prove the validity of this assertion. Moreover, there are bacteria which can develop in a vacuum, and which could find favorable conditions within cans from which the air has been expelled. Sterilization, not the driving out of air, is the important factor in keeping all kinds of canned foods; and although, as we have shown in our earlier paper, the vacuum is necessary in testing the cans, no pre-

serving power can be rightfully ascribed to it. These experiments have been made repeatedly, and always with the result that souring takes place only when living bacteria are present. The presence and activity of the bacteria in sour corn have also been shown by inoculating various kinds of culture media with material from spoiled cans. Active fermentations, of the various kinds previously mentioned, have been brought about in this way.

In order to study these fermentations more thoroughly, and to ascertain, if possible, the source of the bacteria causing them, we spent nearly the whole of the corn-packing season of 1897 at an establishment in Oxford County, Maine, where every convenience for scientific study of the process was kindly put at our disposal by the proprietors. We were thus enabled to investigate thoroughly the methods of procedure, from the harvesting of the green corn to its ultimate shipment in cans.

The Process of Packing.

It is very important that the utmost cleanliness and dispatch should be observed in all the operations, so that the chances of infection from bacteria may be reduced to a minimum. In this factory the strictest caution was exercised in these respects, everything being kept scrupulously clean. The corn is generally picked in the morning, and is delivered to the cannery as early as possible. One or two men make it their special duty to visit the farms once or twice a week during the season to keep informed as to the condition of the crop, and to "order in" the corn as it becomes sufficiently matured. As the ears are delivered at the factory they are arranged in low piles on the ground in an open shed to protect them from the sun. The husks and the silk are taken off by hand, and the corn is then quickly carried to the cutting machines, in which, by a series of knives and scrapers, the kernels are quickly and cleanly separated from the cob. Any stray bits of cob or silk which may be mixed with the corn are now taken out as it passes through the "silker," a machine arranged somewhat on the plan of a gravel-sifter; that is, with two cylindrical wire screens one inside the other, placed on an incline, and rotating in opposite directions. The corn drops through the meshes of the screens, while the refuse passes out at the lower (open) end.

The corn is now weighed, mixed with water in the proper proportions, and is then ready for the cooker. There are several varieties of

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these machines in use, all of which are alike in principle, but differ somewhat in the details of construction. Their object is to heat the corn evenly and quickly to a temperature of 82–88° C. (180–190° F.) and to deliver it automatically into the cans. A single machine fills about thirty cans a minute. The duty of the cooker is threefold: First, in the heating to which the corn is here subjected some of the bacteria, particularly those in the vegetative state, are killed. Second, the corn being filled into the cans while hot expands the air, so that after sealing and cooling a partial vacuum is produced, which, as before stated, is essential for the detection of unsound cans. Finally, this cooking heats the corn to such a temperature that the subsequent sterilization in the retorts is brought about more quickly, and the danger of browning or scorching of the corn next to the tin is minimized.

The cans are next capped, soldered, and tested for leaks. Sterilization, the final and most important step in the whole process, now follows, and is done in retorts, by steam under pressure. The length of heating or processing, and the pressure which is given, vary somewhat in different factories. As we have shown in our previous paper, in practice, in order to insure sterilization it is necessary to obtain and maintain a temperature in excess of 100° C. (212° F.) *throughout the contents of the can*, and for a period of time varying with the substance to be sterilized.

Method of Sterilization.

It is thought by some that intermittent sterilization might be employed in packing, but we consider this entirely impracticable upon a commercial scale. Intermittent sterilization consists in heating to the temperature of boiling water for a length of time varying from thirty minutes to one hour, on three or four successive days, the substance to be sterilized being cooled and kept cool between the heatings. It is supposed that in the first heating all the active bacteria, the so-called vegetative cells, are killed, while the more resistant forms, spores, retain their vitality. According to the theory, the majority of the spores germinate and become active before the second heating, and in turn are killed, while by the third heating all the remaining spores will have developed into active bacteria, and will then be destroyed.

To insure success by this method of sterilization, apparatus and means must be employed which, while practicable in a small way, are

in our opinion absolutely impracticable, on such an extensive scale as would be demanded commercially. To use this method would necessitate at least three times as much sterilizing apparatus, much more room, a greater amount of labor, and a great loss of time.

To show the resistance of bacteria to the continuous action of a boiling temperature, we have found that certain species isolated from sour corn will survive actual boiling for more than five hours, and other species of bacteria which are met with in spoiled canned goods have been boiled for eight hours without being killed. These facts serve to show conclusively the impracticability of the ordinary water bath. On the other hand, the retort with its high temperature will, if properly used, kill all forms of bacteria at a single heating, without injury to the food substance, the length of time required varying, as has already been said, with the conductivity of the medium for heat. We have found by experiment that sixty minutes at 121° C. (250° F.), as indicated by the thermometer on the outside of the retort, is sufficient time for sterilizing corn in two-pound cans, and it seems probable that this can be shortened somewhat, or the temperature reduced. Further experiments are in progress to decide this question.

Whiteness of Canned Corn.

Through a demand that canned corn shall be very light in color, there has been, apparently, a pressure put upon the packer to shorten the time of heating or to reduce the temperature in his retorts. The large losses which have resulted in recent years from sour corn have, it is claimed, been due principally to this demand. Instances are known where the desired result has been brought about by the use of some bleaching reagent, generally sulphite of sodium. While this may not be unwholesome, it greatly injures the flavor of the corn, as a comparison of such corn with that without bleachers will show. Although such cases sometimes occur, it cannot be said to be the fault of the packer; for if the dealers demand very white corn the packer must resort to some unusual means in order to render his product saleable. In this connection a statement in a recent trade journal is noteworthy: "The volume of poor corn which has found its way to market in the last few years has had, and is still having, a considerable effect upon the consumption of that article, and there are a good many families

who never buy canned corn nowadays because they have found little but disappointment in their corn purchases of the last few years."[1]

It is much to be doubted if the consumer demands that the corn be very white in color. What he desires is a palatable article with a natural flavor. It seems evident that in the near future the dealers must regard this very white corn with disfavor, and reject any in this condition.

Maximum Temperature Within the Cans.

By the use of small registering thermometers which can be sealed up within the cans, and which record the maximum temperature reached, we proved, in an extended study of the process as it is actually carried on at the factory, that corn is a very poor conductor of heat, and that the time necessary to bring all portions of the center of the can to the requisite temperature is a factor whose importance cannot be overestimated. Corn as it comes in cans from the cooker is at a temperature of 82 to 88° C. (180 to 190° F.). At the end of thirty minutes in a retort with a pressure of thirteen pounds, the corresponding temperature of which is 118.8° C. (246° F.), a thermometer in the center of a can placed in the middle of the retort, which was full of corn, registered 108.3° C. (227° F.). At the end of forty-five minutes under the same conditions a temperature of 114° C. (237.2° F.) was reached, and at the end of fifty-five minutes the retort temperature of 118.8° C. (246° F.) was registered by the thermometer in the can. From this it is evident that if a packer were giving his corn an hour in the retort at this pressure, the central portions of the can would in reality be subjected to the full effect of the heat for only five minutes. Thus it is evident that with the present methods any reduction of time of heating is attended by considerable risk. If any means could be devised by which the heat could reach more quickly the center of the cans, it might be safe to shorten the time of heating. There is a prospect that before long some such modifications may be possible.

Bacteriology of Sweet Corn.

The source of the bacteria producing the fermentations described was also a problem, the solution of which we sought with great care.

[1] Canner and Dried Fruit Packer, Vol. V, No. 19.

Every step of the process was investigated bacteriologically, and all channels of infection, the water supply for example, were studied. The general cleanliness and the liberal use of water and steam throughout the factory which we visited reduced the liability of infection from dust to a minimum. We examined the green corn on the cob, the corn as it came from the cutting machines, as it went to the cooker, as it came from the cooker, and as it came from the retorts after the usual processing and after some periods of heating given for experimental purposes. Living bacteria were found on the raw corn, and at all stages of the process before the final sterilization. The corn as it went to the cooker was found to contain many germs, but in the short heating to which it was subjected there, some of the organisms were destroyed. Cans which had been retorted for thirty minutes or less were found to contain living bacteria, and cans so treated spoiled and became much distended within four days. No living bacteria were found in cans which had received the full time of processing at this factory. By culture methods and by microscopical examination we have found that the bacteria living upon the kernels of corn and those which are found in the later stages of the process are undoubtedly of the same species. They also correspond in all respects with species which we obtained from cans of sour corn in the laboratory experiments carried on in the early part of our investigations.

All these organisms are characterized by great rapidity of growth when allowed to develop at a temperature of 37° C. (98.6° F.). In evidence of this fact we need only to state that of the large number of cans incubated at this temperature many swelled within twenty-four hours, while in several cases the cans exploded within that time. Agar streak-cultures of these bacteria frequently showed well-marked growth within six hours, and in some cases in four hours. The growth is much retarded at a temperature of 20° C. (70° F.). None of the organisms which we have obtained correspond closely to the published descriptions of the lactic or butyric acid organisms, or to that of the *Bacillus maidis* of Cuboni.

If sour corn is the result of bacterial action, the question naturally arises, Why should a packer have trouble in a certain year, when he is using presumably the same methods of treatment that he has employed without loss in former years? A number of conditions might exist that would account for this. In the first place, it is a well-known fact that diseases which are caused by bacteria may be much more preva-

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lent in some years than in others. The same is probably true in the case of the bacteria which attack corn. The weather may be much more favorable for the growth of these germs in certain years than in others, and there is good reason to believe that a warm moist season is more apt to give sour corn than a cool dry one. Is the packer entirely sure that the conditions prevailing within the factory are always the same from year to year? Other things being equal, if exactly the same methods are used, similar results should be obtained. But to all outward appearances the conditions may be the same, when in reality they are quite different. Differences in the steam gauges or thermometers, or a little carelessness on the part of some operative, may be sufficient to turn the scale and give rise to sour corn where before none had existed. That trouble might be caused by such slightly changed conditions can be seen readily when we realize that, as we have already shown, in being processed in the retort for an hour at a temperature of 240° C., or over, the corn at the center of the can is in reality only receiving this intensity of heat for five minutes.

Believing that, in order to be of practical value, all laboratory experiments must be carried on under conditions as nearly as possible like those existing in the factory, we have recorded only such results as have been obtained under these conditions. There are still some facts to be determined which cannot be settled by laboratory experimentation, and which, owing to the shortness of the packing season, we were unable to push to completeness last year. We hope another year to investigate these points more fully.

We wish to express our gratitude and indebtedness to all those who have so kindly helped us, and particularly to Professor Sedgwick, without whose coöperation this work would have been long delayed.

In conclusion we would again affirm:

1. That sour corn appears to be always the result of bacterial action, and due to imperfect sterilization.

2. That in case of insufficient processing souring does not always result unless the cans are subjected to conditions favorable to the growth of the bacteria within.

3. That the bacteria which produce sour corn are found on the kernels and beneath the husks of the corn as it comes from the field.

4. That the bacteria found on the ears of corn correspond in all respects to those originally found by us in cans of sour corn.

5. That swelling may be caused by bacteria other than those which produce sour corn, but it is also a natural consequence and a further development of this process of souring, provided the cans be subjected to a favorable temperature.

6. That so far as we have been able to discover, the organisms present in sour corn are capable of producing serious commercial damage and an unpleasant taste, but are otherwise harmless.

7. That a vacuum is not necessary for the preservation of canned foods, but is a valuable factor in the detection of unsound cans.

8. That the use of bleachers is not to be recommended, and is unnecessary if proper methods of sterilization be employed.

9. That the utmost cleanliness at every step is absolutely essential.

10. That intermittent sterilization is not practicable on a commercial scale.

11. That the open water bath is inefficient as a means of sterilization.

12. That with the present methods of retorting it takes fifty-five minutes for the temperature which is indicated on the outside thermometer to be registered at the center of a two-pound can of corn previously heated in the cooker to 82 to 88° C. (180 to 190° F.).

13. That heating for ten minutes with a temperature of 126° C. (250° F.) throughout the whole contents of such a can of sweet corn, appears to be sufficient to produce perfect sterilization.

Biological Laboratory,
Massachusetts Institute of Technology, Boston,
January 4, 1898.

APPENDIX.

DESCRIPTIONS OF BACTERIA FOUND.

BACILLUS A.

OCCURRENCE.	Found in cans of sour corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Bacillus, occurring singly and in short chains. *Size:* Generally 2–4μ long by 1μ broad. Many cells are very long, and vary from 10–50μ in length. *Motility:* Rapid serpentine and spinning movements. *Spore formation:* Oval, centrally located spores. *Relation to temperature:* Develops rapidly at 37½° C.; more slowly at 20° C. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Liquefies. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Develops rapidly throughout whole length of puncture. Liquefaction begins within twenty-four hours, and at the end of two days a horn-shaped liquefied portion is observed. *Plate culture:* Surface colonies: Very small. Liquefaction begins almost as soon as colonies are visible; in two days the plate culture is entirely liquid. Submerged colonies: Apparently same as on surface.
AGAR.	*Streak culture:* A thin, smooth layer, covering nearly the whole surface. Edges dissected and bluish in color. In two days lower part of culture becomes dryer, white, and finely wrinkled. *Plate culture:* Surface colonies: Vary much in size and shape. Young colonies are very small, oval or circular. Spreading soon begins, giving irregularly branched or suliate colonies. Submerged colonies: Very small, oval or spherical.
POTATO.	Potato much darkened. A thin film of growth cövers the surface. This film is at first moist, but at end of three days becomes dry and finely wrinkled.
MILK.	Not coagulated. Acidity: strong.
SMITH SOLUTION.	No gas produced. Thin film on surface. Sediment at bend of tube. Turbid throughout. Strongly acid.
NITRATE.	Is reduced to nitrite. Solution clear.
BOUILLON.	Slightly turbid at end of twenty-four hours at room temperature. Film develops in twenty-four hours in incubator at 37½°. No sediment.

BACILLUS B.

OCCURRENCE.	Found in cans of sour corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Bacilli, occurring singly and in short chains. *Size:* 2–5μ long by .6μ broad. *Motility:* Slightly motile. *Spore formation:* Very small oval spores. *Relation to temperature:* Develop more rapidly at 37½° C. than at 20° C. *Relation to air:* Aërobic, facultatively anaërobic. *Relation to gelatin:* Liquefy slowly. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Growth well marked throughout entire length of line of inoculation. A small cup-shaped depression is observed on second day. This increases in size slowly as liquefaction occurs. *Plate culture:* Surface colonies: First appear as small, translucent blue dots, which later become white or gray, and slowly liquefy the plate. Colonies from $\frac{1}{8}''$ to $\frac{3}{16}''$ in diameter. Submerged colonies: Small and blue when seen by transmitted light.
AGAR.	*Streak culture:* A thick, white, milky layer, covering the whole surface of the agar. The lower portion becomes somewhat wrinkled. *Plate culture:* Surface colonies: Shiny, almost porcelain white in color. When about $\frac{1}{32}''$ in diameter often send out little branches or processes on one side, giving a very characteristic appearance. Submerged colonies: Small, spherical dots.
POTATO.	Drab growth spreading over whole surface of potato, and moist and somewhat wrinkled in appearance. Potato much darkened.
MILK.	Not coagulated in two days. Acid in reaction.
SMITH SOLUTION.	No gas produced. Solution acid in reaction. Growth throughout tube. Sediment at bend and film on surface.
NITRATE.	Not reduced to nitrite.
BOUILLON.	Faintly turbid at end of twenty-four hours at 20° C. At 37½° C. a dry looking film appears on surface in from twelve to twenty-four hours.

BACILLUS C.

OCCURRENCE.	Found in cans of sour corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Bacilli, with rounded ends, occurring in chains. *Size:* 3–9μ x 1.8μ. *Motility:* The chains swim with slow, steady, undulating motion. *Spore formation:* Large, oval, centrally located spores. *Relation to temperature:* Develop rapidly at 37½° C.; more slowly at 20° C. *Relation to air:* Aërobic and facultatively anaërobic. *Relation to gelatin:* Liquefy readily. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Growth throughout, but most abundant at surface. A trumpet-shaped, liquefied portion is quickly formed, with flocculent material in suspension and precipitate at bottom. Film on surface. *Plate culture:* Surface colonies: At first white and small. As soon as they break through the surface liquefaction commences, and colonies rapidly become large and of a homogeneous gray color. At end of a week colonies are 1″ in diameter and covered by a thin film, with concentric markings and fluted edges. Submerged colonies: Rounded and white. Soon break surface of gelatin and begin to liquefy.
AGAR.	*Streak culture:* Thick granular layer, with dull luster. Edges sharply defined and scalloped. At end of two or three days wrinkles appear on older portion. *Plate culture:* Surface colonies: Smooth and somewhat waxy in appearance. Often spread to form irregularly shaped patches with thickened edges. Submerged colonies: Small when separated, but often unite, forming a thin film on lower surface of the agar.
POTATO.	A rather abundant yellowish layer of dull, waxy luster. Potato darkened.
MILK.	Is coagulated with clear separation of whey. Acidity: Slight.
SMITH SOLUTION.	No gas produced. Very heavy sediment. Solution comparatively clear. Strongly acid.
NITRATE.	Is reduced to nitrite strongly. Slight turbidity.
BOUILLON.	Strongly turbid throughout at end of twenty-four hours at 20° C. After twenty-four hours at 37½° C. a slight amount of sediment is formed, and a ring of growth appears at the surface.

BACILLUS D.

OCCURRENCE.	Found in cans of sour corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Bacilli, occurring singly and in chains. *Size:* 3.5–10μ x 2μ. *Motility:* Chains not motile. Single cells move with slow serpentine motion. *Spore formation:* Spores formed in center or near one end. *Relation to temperature:* Develops rapidly at 37½° C. *Relation to air:* Aërobic and facultatively anaërobic. *Relation to gelatin:* Liquefy. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Growth slight, but noticed throughout. Liquefaction soon begins. *Plate culture:* Surface colonies: First appear as white dots. Liquefaction begins quickly, and a liquefied saucer-shaped depression, with a white dot at center, is soon formed. Colonies rapidly become large, and have flocculent precipitate near center and finger-like processes projecting inward from edges. At end of a week the plate is nearly all liquefied and a thin film is developed at surface. Submerged colonies: Few and small.
AGAR.	*Streak culture:* Thick, slimy growth readily removed. It occurs in form of scalloped patches, with smooth edges. *Plate culture:* Surface colonies: White or gray, regular in outline, and smooth and shiny when young. Later become somewhat irregular in shape. Submerged colonies: First appear like woolly or burr-like rounded masses, which soon break through surface and become shiny and smooth, like surface colonies.
POTATO.	At end of three days a thick, spreading growth, dull white in color, and looking like a piece of wet cracker. Irregular edges. Potato not discolored.
MILK.	Partially coagulated in two days. Acidity: Marked.
SMITH SOLUTION.	No gas produced. Turbid throughout. Considerable sediment. Very strongly acid.
NITRATE.	Is reduced to nitrite faintly. Slight turbidity and sediment.
BOUILLON.	Turbid throughout at end of first day. A thin film is formed after several days.

BACILLUS E.

OCCURRENCE.	Found in sour corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Long, narrow bacilli, generally occurring singly. Very variable in size. *Size:* 2–50μ x .6μ. *Motility:* Move rapidly, with eccentric darting and twisting movements. *Spore formation:* Small, oval, centrally located. *Relation to temperature:* Develops rapidly at 37½° C.; slower at 20° C. *Relation to air:* Aërobic and facultatively anaërobic. *Relation to gelatin:* Non-liquefying. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Slight spreading growth at surface, and growth all along line of inoculation. Filmy, ragged surface. Growth at end of second day. Transparent. *Plate culture:* Surface colonies: Circular; bluish by transmitted light. Grow to about ⅛″ in diameter. Submerged colonies: Small white dots, developing more slowly than surface colonies.
AGAR.	*Streak culture:* In growth very similar to A. Bluish edges, finely dissected. Surface of agar covered with a thin, white layer, finely wrinkled at the base. *Plate culture:* Surface colonies: At first small, rounded masses, which on third or fourth day show a thin surrounding outgrowth, appearing bluish by transmitted light. Submerged colonies: Many small colonies about size of pin points.
POTATO.	A yellowish growth along line of inoculation. On lower part of surface a thin, wrinkled film extends. Potato slightly darkened. Young growth moist in appearance.
MILK.	Not coagulated. Acidity: strong.
SMITH SOLUTION.	No gas produced. Solution turbid throughout. Sediment at bend. Thick film on surface. Slightly acid.
NITRATE.	Not reduced. Considerable turbidity.
BOUILLON.	Faintly turbid throughout at end of twenty-four hours at room temperature. Tough, thin, wrinkled film at end of twenty-four hours in incubator.

BACILLUS S.

OCCURRENCE.	Found on ears of green corn and in cans of sour corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Bacilli, generally occurring singly, but frequently in chains of three or four. *Size:* 2–10μ x 1–1.8μ. Average: 3–4μ x 1.5μ. *Motility:* Quick swimming motion; chains also motile. *Spore formation:* Small, oval, centrally located spores. *Relation to temperature:* Develops more rapidly at 37½° C. than at 20° C. *Relation to air:* Aërobic and facultatively anaërobic. *Relation to gelatin:* Liquefies rapidly. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Growth throughout in twenty-four hours. Liquefaction at surface. Thick film, marked with concentric rings on surface. At end of a week liquefaction extends to walls and ¼″ down from surface. *Plate culture:* Surface colonies at end of two days are small, and white or bluish in color. Liquefaction begins about the third day, and proceeds slowly until the whole plate is liquid. Colonies form saucer-shaped depressions with a central disk of gray color and sharply defined edges. Submerged colonies: Small, irregular, and hazy in outline.
AGAR.	*Streak culture:* A thin, smooth, shiny, transparent layer, with bluish color and scalloped edges, covering nearly the whole surface. *Plate culture:* Surface colonies first appear as small, round, white spots. Spreading soon begins, and stellate or branched colonies, with bluish fluorescence, are formed. If many colonies are present on the plate the branching is less conspicuous, and the plate soon becomes covered with a thin layer.
POTATO.	A yellowish, moist, slimy layer extends over the whole surface. The potato is wet in appearance and very much darkened in color.
MILK.	Not coagulated. Acidity: strong.
SMITH SOLUTION.	No gas produced. Slightly turbid throughout. Film on surface. Neutral reaction.
NITRATE.	Is reduced to nitrite slightly. Solution turbid.
BOUILLON.	Turbid throughout at end of twenty-four hours at 20° C. At end of a week slight surface growth, considerable cloudiness, but no sediment.

BACILLUS T.

OCCURRENCE.	Found in cans of sour corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Rods occurring singly in short chains. *Size:* 2–4μ x 1μ. *Motility:* Slightly motile. *Spore formation:* Oval spores, filling nearly the whole cell. *Relation to temperature:* Develops more rapidly at 37.5° C. than at 20° C. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Liquefies. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Development all along line of inoculation in twenty-four hours. Liquefaction takes place, forming a trumpet-shaped mass, somewhat depressed at surface. A film develops on surface, and a flocculent substance is held in suspension. *Plate culture:* Surface colonies first appear as small spots. Soon liquefaction begins, forming a cup-shaped depression, with a central, whitish mass. At end of a week a thick, waxy scum, marked by concentric rings, covers the entire surface.
AGAR.	*Streak culture:* Thick, gray film, with irregular edges. Dull, granular mat surface on lower portion, and smooth and lustrous above. *Plate culture:* Surface colonies: Grayish or brownish in color, irregular in outline. Thickened edges; sometimes a dot is seen at center. Submerged colonies: Like surface colonies in general appearance.
POTATO.	Thick, white growth, with dull luster spreading over surface. Potato darkened.
MILK.	Partially coagulated in two days. Acidity: slight.
SMITH SOLUTION.	No gas produced. Very turbid throughout. Ring of growth at surface. Strongly acid.
NITRATE.	Is reduced to nitrite strongly. Turbid.
BOUILLON.	Becomes turbid within twenty-four hours. Thin, flaky surface growth, which breaks up and settles, forming a deposit. Waxy film.

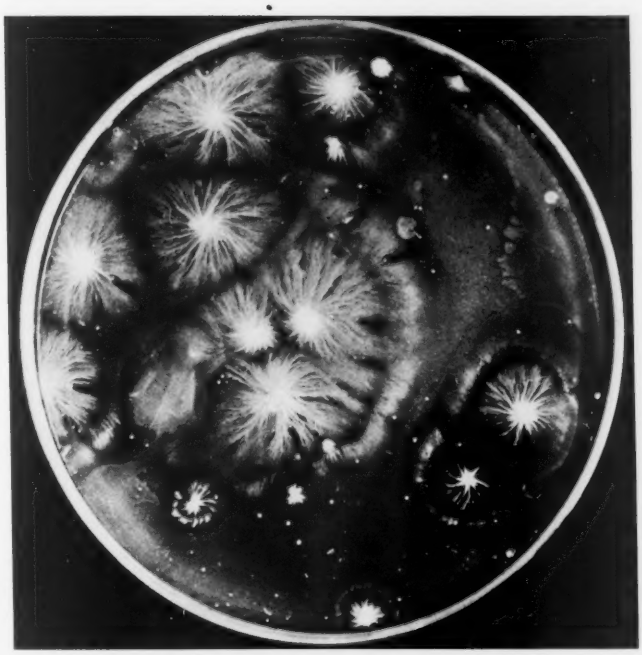
BACILLUS U.

OCCURRENCE.	Found on ears of green corn and in cans of spoiled corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Rods occurring singly and in chains of two or three elements. *Size:* Variable — 2 to 16μ x 1.5μ. *Motility:* Rapid, serpentine, and spinning motion. *Spore formation:* Oval spores formed. *Relation to temperature:* Develop rapidly at 37½° C., more slowly at 20° C. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Liquefy. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* At end of first day faint growth along needle track. On second day slightly liquefied at surface. Liquefaction spreads rapidly to wall of tube, and whole upper portion soon becomes liquid. *Plate culture:* Surface colonies: When very small show slight branching, but as soon as liquefaction begins colonies become circular and form depressions in the gelatin. Plates become entirely liquid in a few days. Submerged colonies: Small, spherical, and inconspicuous.
AGAR.	*Streak culture:* Smooth, white, shiny layer, with branched or serrated edges, and extending over nearly the whole surface. *Plate culture:* Surface colonies: Circular when very young, but branching takes place as colonies develop, producing stellate forms. The fewer the colonies the more marked the branching.
POTATO.	Growth rapid, and extends over the whole surface of the potato. In early stages appears drab and slimy, but darkens with age, and becomes somewhat dry and wrinkled, like a paint skin. Potato darkened.
MILK.	Not coagulated. Acidity: strong.
SMITH SOLUTION.	Much gas produced. Heavy sediment. Turbid throughout. Very strongly acid.
NITRATE.	Is reduced to nitrite faintly. Solution clear.
BOUILLON.	Turbid throughout at end of twenty-four hours in incubator. Sediment and film.

[illegible]

PLATE CULTURES, SHOWING COLONIES OF BACILLUS U.
(Actual size.) Found in Cans of Sour Corn.

[illegible]



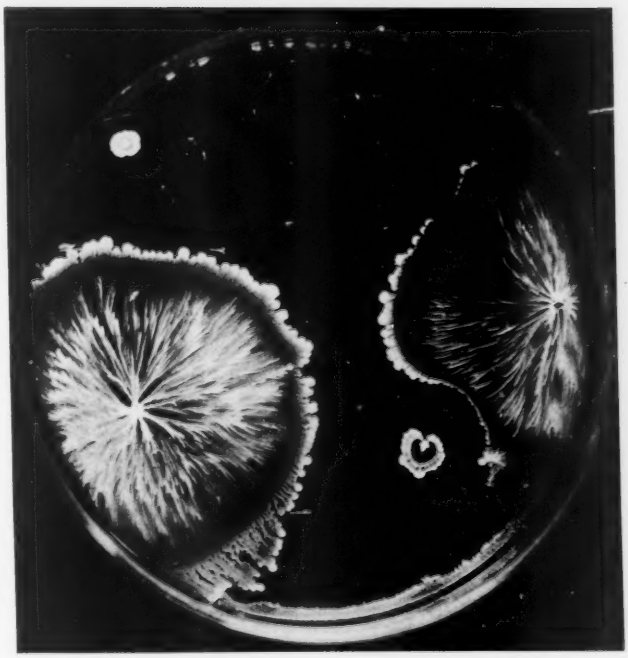
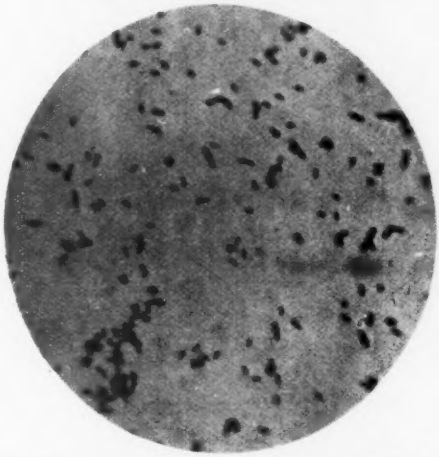
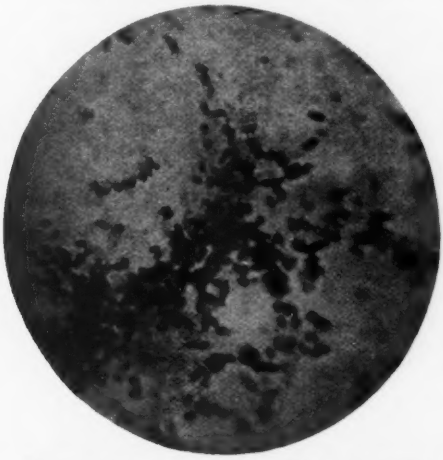


PLATE CULTURES, SHOWING COLONIES OF BACILLUS U.
(Actual size.) Found under Husks of Green Corn.

BACILLUS U. VEGETATIVE STATE FROM BOUILLON. (Magnified 1,000 times.)



BACILLUS U. VEGETATIVE STATE FROM AGAR. (Magnified 1,000 times.)



BACILLUS U. SPORES. (Magnified 1,000 times.)

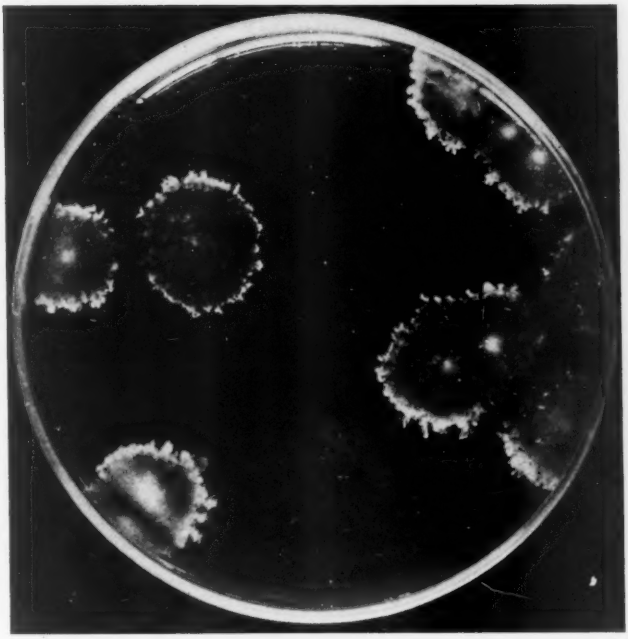


PLATE CULTURE, SHOWING COLONIES OF BACILLUS W AT END OF 48 HOURS. (Actual size.)
Found under Husks of Green Corn.

BACILLUS W.
(Magnified 1,000 times.)

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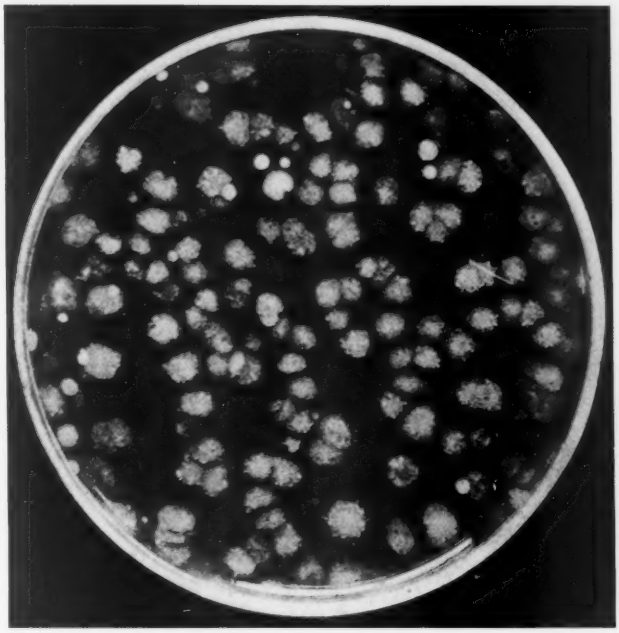


PLATE CULTURE, SHOWING COLONIES OF BACILLUS W AT END OF 24 HOURS. (Actual size.)
Found in Cans of Sour Corn.

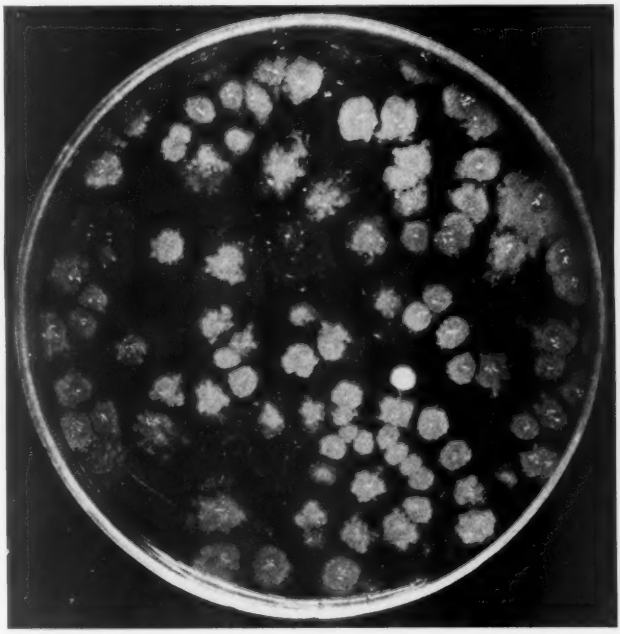


PLATE CULTURES, SHOWING COLONIES OF BACILLUS W AT END OF 24 HOURS. (Actual size.)
Found under Husks of Green Corn.

BACILLUS W.

OCCURRENCE.	Found on ears of green corn and in cans of corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Stout rods, rounded ends, generally in chains. *Size:* 4–6μ x 1.8–2μ. *Motility:* Swim rapidly with undulating motion. *Spore formation:* Oval spores centrally located. *Relation to temperature:* Develops rapidly at 37½° C., slowly at 20° C. *Relation to air:* Aërobe and facultative anaërobe. *Relation to gelatin:* Liquefies rapidly. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Development well marked at end of twenty-four hours. On second day a large trumpet-shaped mass of liquefied gelatin is formed, in which is suspended a heavy flocculent precipitate. *Plate culture:* Surface colonies: Circular, rapidly growing, and containing a gray or brown precipitate at center, surrounded by a broad ring of clear, liquefied gelatin. On long standing surface becomes covered with a thin, scaly film or incrustation. Submerged colonies: Small, circular or oval.
AGAR.	*Streak culture:* A thick, finely-granular layer, with bluish irregular and indistinct edges covering nearly the whole surface of the agar. *Plate culture:* Surface colonies: Granular, brownish-gray colonies, of rather dull luster, irregular in shape and thickened at the edges. Young colonies appear somewhat finely branched or woolly.
POTATO.	An abundant white, spreading layer, with dull, somewhat waxy luster. Edges somewhat thickened and whiter than central portion. Potato slightly darkened.
MILK.	Totally coagulated. Acidity: strong.
SMITH SOLUTION.	No gas produced. Slightly turbulent. Heavy sediment. Strongly acid.
NITRATE.	Is reduced to nitrite strongly. Turbid throughout.
BOUILLON.	Turbid throughout. Ring of growth at surface and slight amount of sediment.

MICROCOCCUS X.

OCCURRENCE.	Found in sour corn and on ears of green corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Micrococci, occurring singly and in irregular clusters. *Size:* 1μ in diameter. *Motility:* Not motile. *Spore formation:* Not observed. *Relation to temperature:* Develop well at 37½° C., slowly at 20° C. *Relation to air:* Aërobic and facultatively anaërobic. *Relation to gelatin:* Does not liquefy. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Development slow; growth throughout somewhat raised at surface, forming a small button-like mass. *Plate culture:* Surface colonies: Sharp outline, raised above surface, concentric markings, bluish white in color, and of somewhat waxy luster. Submerged colonies: Small, spherical.
AGAR.	*Streak culture:* Growth closely follows line of inoculation. Bluish white, semi-translucent, lustrous, and moist. *Plate culture:* Surface colonies: Circular and somewhat dome-shaped. White in color. Develop in about three days. Submerged colonies: Small, oval or rounded.
POTATO.	Very meager growth at end of three days. White and shiny. After two weeks becomes dry and almost exact color of potato.
MILK.	Not coagulated. Acidity: slight.
SMITH SOLUTION.	No gas produced. Slight turbidity. Some sediment. Slightly acid reaction.
NITRATE.	Not reduced to nitrite.
BOUILLON.	Slight turbidity at end of twenty-four hours at 37½° C. On standing a heavy sediment is deposited and solution becomes clear.

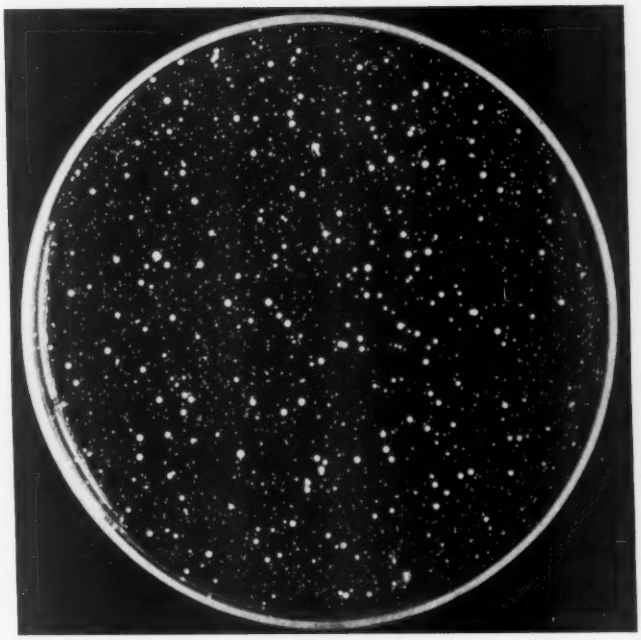
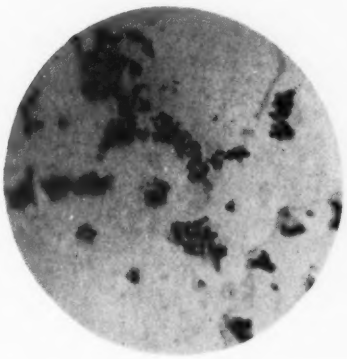


PLATE CULTURE, SHOWING COLONIES OF MICROCOCCUS X.

(Actual size.)

Found under Husks of Green Corn.



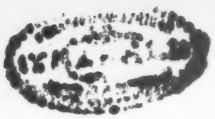
MICROCOCCUS X.

Taken from Above Colonies.

(Magnified 1,000 times.)

BACILLUS Y.

OCCURRENCE.	Found in cans of sour corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Stout, thick rods, occurring singly and in chains. *Size:* 4–5μ x 2.5μ. *Motility:* Slow, serpentine motion; chains also motile. *Spore formation:* Oval spores. *Relation to temperature:* Develops more rapidly at 37½° C. than at 20° C. *Relation to air:* Aërobic and facultative anaërobe. *Relation to gelatin:* Liquefies rapidly. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Growth throughout in one day, and liquefaction already begun at surface; much increased on second day, and flocculent precipitate in lower part of liquefied portion. Gelatin finally becomes entirely liquid, and heavy sediment formed. *Plate culture:* Surface colonies: Circular and rapidly liquefying; soon become covered with film. Saucer-shaped depression formed, at center of which is a flocculent, suspended mass, surrounded by ring of clear liquid. Submerged colonies: Small and inconspicuous.
AGAR.	*Streak culture:* Very thick, much-wrinkled layer, white and somewhat shiny. Edges finely scalloped. *Plate culture:* Surface colonies first appear as small dots; later form irregular spreading growths of varying thickness. Submerged colonies: Thin, blue, irregular in outline.
POTATO.	Thick, white layer, somewhat granular in appearance. On thickest portion of potato growth has a faint luster.
MILK.	Totally coagulated. Acidity: strong.
SMITH SOLUTION.	No gas produced. Turbid throughout. Strongly acid.
NITRATE.	Is reduced to nitrite strongly. Some turbidity.
BOUILLON.	Development slow. Liquid remains clear, but a film is formed on surface and a heavy, flaky sediment produced by sinking of film.



BACILLUS Z.

OCCURRENCE.	Found in cans of sour corn.
GENERAL CHARACTERS.	*Shape and arrangement:* Bacilli, occurring singly and in long chains. *Size:* 3.5–7μ x 2μ. *Motility:* Moves with slow serpentine motion. *Spore formation:* Small oval, centrally located spores. *Relation to temperature:* Develops rapidly at 37½° C., more slowly at 20° C. *Relation to air:* Aërobic and facultatively anaërobic. *Relation to gelatin:* Liquefying. *Color:* Non-chromogenic.
GELATIN.	*Stick culture:* Growth throughout and liquefaction at surface at end of first day. On second day liquefaction had spread to walls of tube, a wrinkled film was present on surface, and flocculent precipitate in suspension. *Plate culture:* Surface colonies develop rapidly. When about $\frac{1}{16}''$ in diameter liquefaction begins. A central area of flocculent material is present. At end of a week colonies are large, and are covered by a thick film of waxy appearance and showing concentric rings. Submerged colonies: Small.
AGAR.	*Streak culture:* A thick, white layer, of rather dull luster and finely granular appearance, covers the whole surface of the agar. *Plate culture:* Surface colonies: Irregular in outline, slightly thickened at the center. Brown and somewhat shiny. Some colonies show irregular outgrowths and appear woolly. Submerged colonies: Spread on lower surface of agar, forming a thin layer, which appears bluish by transmitted light.
POTATO.	Abundant white growth covering nearly the whole surface. Somewhat dull and granular in appearance.
MILK.	Totally coagulated in two days. Acidity: strong.
SMITH SOLUTION.	No gas produced. Turbid throughout. Sediment at bend; ring of growth at surface. Strongly acid.
NITRATE.	Is reduced to nitrite strongly. Slight turbidity.
BOUILLON.	Strongly turbid throughout at end of twenty-four hours at 20° C. Growth at surface and flaky sediment when grown at 37½° C.

RESULTS OF TESTS MADE IN THE ENGINEERING LABORATORIES.

IX.

Steam and Hydraulics.

Description and Results of Two Tests on No. 1 Babcock & Wilcox Boiler with Hawley Down Draught Furnace, at the Massachusetts Institute of Technology, January 13, 14, 15 and 16, 1897.

These tests, which served as a part of the regular work of the Engineering Laboratories, were made by the students under the direction of the regular instructing force of the laboratories.

The tests were divided up into watches of about eight hours each, six men working in each watch.

The different stations were as follows:

Stations.

(1) Coal, ash, log. Temperature of room. Temperature of outside air. Boiler pressure every fifteen minutes. Barometer.

(2) Weight of water fed.

(3) Calorimeter every thirty minutes, ten-minute test.

(4) Gas analysis base of stack. Sample taken on the hour. Temperature of feed water every fifteen minutes.

(5) Gas analysis every hour, taken on the half-hour. Draught and temperature of flue at base of stack every thirty minutes.

(6) Draught and temperatures at different landings above basement every hour.

Arrangements for the Test.

With the exception of the feed pipe, all pipes entering the water space of the boiler were disconnected and blanked, thus preventing all chance of leakage. The boiler was fed by a duplex pump connected

with this boiler only. The suction of this feed pump was taken from a barrel to which water was supplied from a second barrel placed on scales directly over the first barrel. An auxiliary pump served to feed boiler No. 3, and also to pump the returns from the heating system into the barrel on scales. The temperature of the feed water was taken from a thermometer inserted in a cup screwed into the feed pipe close to the boiler. A throttling calorimeter was connected to the steam main about 7 feet from the boiler, the quality of the steam being determined every thirty minutes. Samples of flue gases were taken at frequent intervals from the chimney about 8 feet above the grate.

Seven hundred and fifty pounds of coal were weighed out every hour and dumped in front of the boiler.

A sample of coal was taken from each barrow as it left the pocket, and the per cent. of moisture in the coal was determined from these samples. The coal was thoroughly wetted before firing.

All gauges and thermometers used were tested, and their errors determined. The weighing scales were verified with sealed weights.

In connection with the test on the boiler, readings of temperature and draught were taken at five different levels in the chimney. The chimney is unlined 3′ x 3′ inside with 8″ walls, and is 102 feet in height above the grate. All but about 15 feet of the chimney is inside the building.

Observations as to the amount and density of the smoke issuing from the chimney were taken by one of the instructing staff.

Starting and Ending the Test.

The tests were started with the boiler running at its usual rate and with good fires on the grate. At the time of starting the pressure and water level were observed, and the thickness of the fires both on the upper and lower grates noted. At the end of the tests the fires were brought, as near as could be judged, to the same condition and to the same thickness as at starting.

Remarks.

The test was divided into two parts. During the first thirty-one hours New River coal was used; during the last forty-eight hours Pocahontas coal was used. The New River was of the same grade

that had been furnished to the Institute. The Pocahontas was of good quality, the greater part being in lumps.

During the day watches, the firing was done by an expert fireman furnished by the Hawley Furnace Company. During the night, the firing was done by the regular fireman.

Fires were cleaned three hours before starting each test and three hours before ending each test, and at such other times as seemed advisable. Tubes were blown each night at about midnight.

It was shown by the gas analysis that a great excess of air was admitted, the per cents of O and CO_2 being reversed from what they should have been. Probably a large part of this excess air leaked in around the tiles supported on the boiler tubes directly over the upper grate.

The greatest possible error of the first test is not greater than $\frac{8}{10}$ of 1 per cent. The greatest possible error of the second test is not over $\frac{6}{10}$ of 1 per cent.

BOILER TEST.

Date, January 13–14, 1897.

Duration of test	31 hrs.
Average pressure of air	14.7 lbs.
Average pressure of steam	109.4 lbs.
Average temperature of feed water	123.26° F.
Coal used was New River	New River.
Moisture in coal (2.9 %)	2.9 %
Boiler was 208 H. P. (rated) B. & W., with Hawley furnace	B. & W.
Grate surface of upper grate	34.22 sq. ft.
Heating surface	2291.0 sq. ft.
Heating surface to grate surface	67 to 1
Pounds coal weighed out	23,250 lbs.
Dry coal burned	22,576 lbs.
Refuse from coal	1,438 lbs.
Combustible	21,138 lbs.
Quality of steam (dry steam = 1)	.992
Total water pumped into the boiler	221,203 lbs.
Equivalent water evaporated from and at 212°	249,296 lbs.
Equivalent water evaporated into dry steam from and at 212° F. per pound of dry coal	11.04 lbs.
From and at 212° per pound of combustible	11.79 lbs.
Coal per square foot upper grate per hour	21.9 lbs.
Water from and at 212° per square foot heating surface per hour	3.51 lbs.
Boiler H. P. developed (A. S. M. E. rating)	233 H. P.
Per cent. excess over rating (208)	12. %

BOILER TEST.

Date, January 14, 15, 16, 1897.

Duration of test	48 hrs.
Average pressure of air	14.7 lbs.
Average gauge pressure	113.4 lbs.
Average temperature of feed water	120.74° F.
Coal used was Pocahontas	Pocahontas.
Moisture in coal (1.9%)	1.9%
Boiler was 208 H. P., B. & W., with Hawley furnace	B. & W.
Grate surface of upper grate	34.22 sq. ft.
Heating surface	2291 sq. ft.
Heating surface to grate surface	67 to 1
Pounds coal weighed out	36,000 lbs.
Dry coal burned	35,316 lbs.
Refuse from coal	1,350 lbs.
Combustible	33,966 lbs.
Quality of steam (dry steam = 1)	.992
Total water pumped into boiler	349,767 lbs.
Equivalent water evaporated from and at 212° F.	395,326 lbs.
Equivalent water evaporated into dry steam from and at 212° per pound of dry coal	11.19 lbs.
From and at 212° per pound of combustible	11.64 lbs.
Coal per square foot of upper grate per hour	21.9 lbs.
Water from and at 212° per square foot heating surface per hour	3.60 lbs.
Boiler H. P. developed (A. S. M. E. rating)	239 H. P.
Per cent. excess over rating (208)	14.9%

Smoke Tests.

These observations were taken on January 14 and 15, 1897, to determine the grade of smoke issuing from the chimney of No. 1 Babcock & Wilcox boiler, with Hawley furnace.

On account of the difficulty of estimating the grade of smoke by the eye alone, it seemed best to rate the smoke by means of some device which would eliminate personal judgment as far as possible.

The apparatus used was made up of pieces of smoked glass so arranged in a fixed frame that the observer could, with but little motion of his head, observe the smoke through one, two, three, four, five or six thicknesses of the glass.

The observations, which were taken from the top of the Walker Building at the Massachusetts Institute of Technology about 200 feet from the chimney, consisted in noting the number of thicknesses of the glass which just obscured the smoke, and the period of time that the smoke was covered by any given number of thicknesses.

Although the method is rather unsatisfactory, and the apparatus crude, yet it gives us a means of telling at any time, more accurately than could be told by the eye alone, how the amount of smoke compares with that noted during the test.

A smoke visible through four thicknesses of glass, but not visible through five, would be recorded as in grade No. 5. No. 6 denotes very black smoke; No. 4 corresponds to what is indefinitely called 10 per cent. smoke. A few of the observations taken are given in the following table:

NEW RIVER COAL.

January 14, 1897. Sky, light gray.

Time smoke noticed.	No. of glasses.	Duration.		Time smoke noticed.	No. of glasses.	Duration.	
h. min. sec.		min.	sec.	h. min. sec.		min.	sec.
1 32 0	3	..		38 30	6	..	15
32 30	2	..	30	38 40	5	..	10
33 20	3	..	50	38 50	4	..	10
33 35	0	..	15	39 5	3	..	15
34 5	5	..	30	39 20	2	..	15
34 15	4	..	10	40 10	0	..	50
34 25	1	..	10	40 45	3	..	35
34 35	5	..	10	41 05	2	..	20
34 45	4	..	10	41 15	4	..	10
35 5	0	..	20	41 30	2	..	15
38 5	4	3	0	41 40	0	..	10
38 15	5	..	10				

SUMMARY OF SMOKE RESULTS. NEW RIVER COAL. January 14, 15, 1897.

Time, 1.32 to 4.02 P. M., or 150 minutes interval. Sky, light gray.

PER CENTS. OF TOTAL TIME THAT THE SMOKE WAS COVERED BY EACH OF THE DIFFERENT NUMBERS.

No. 0	23.4%
1	1.9%
2	15.1%
3	16.6%
4	24.5%
5	14.8%
6	3.7%
	100.0%

SUMMARY OF SMOKE RESULTS. POCAHONTAS COAL.

January 15, 1897.

Observations were taken from 9.26 A. M. to 11.56 A. M.		Observations were taken from 1.35 P. M. to 4.05 P. M.	
No. 0	41.0	No. 0	47.2
1	14.0	1	16.1
2	10.0	2	7.8
3	8.4	3	12.8
4	14.7	4	10.4
5	10.2	5	4.9
6	1.7	6	0.8

BRIEF SUMMARY OF BOILER TEST RESULTS NEEDED FOR SMOKE COMPARISON.

Area upper grate (square feet)	34.22	34.22	
Area lower grate (square feet)	35.0	35.0	
Heating surface (square feet)	2291	2291	
Kind of coal used	New River.	Pocahontas.	
Coal fired each hour (pounds)	750	750	
Boiler rating (A. S. M. E.)	208	208	
Boiler H. P. developed	233	239	
Draught at base of stack (inches of water)	.614″	.599″	
Temperature of gases at base of stack	467° F.	453° F.	
Carbonic acid, per cent. by vol. in flue gases	7.30	7.92	
Carbonic oxide, per cent. by vol. in flue gases	0.10	0.12	
Free oxygen, per cent. by vol. in flue gases	12.32	11.47	
Time smoke observations taken	1.32 to 4.02	9.26 to 11.56	1.35 to 4.05
Condition of sky	Light gray.	Light gray.	Blue.
Per cent. of total time covered by No. 0	23.4	41.	47.2
Per cent. of total time covered by No. 1	1.9	14.	16.1
Per cent. of total time covered by No. 2	15.1	10.	7.8
Per cent. of total time covered by No. 3	16.6	8.4	12.8
Per cent. of total time covered by No. 4	24.5	14.7	10.4
Per cent. of total time covered by No. 5	14.8	10.2	4.9
Per cent. of total time covered by No. 6	3.7	1.7	0.8

TESTS ON A RIDER COMPRESSION HOT AIR ENGINE.

Date.	Revolutions per minute.	M. E. P. working cylinder.	M. E. P. compression cylinder.	Total lift.	Apparent capacity. (Gals. per minute.)	Real capacity. (Gals. per minute.)	Horse power indicated.	Horse power by pump.	Mechanical Efficiency.
1896.									
Dec. 11	138.0	13.6	7.50	88.84	12.03	10.51	.812	.236	29.0
Dec. 8	128.3	13.1	8.02	96.0	11.18	9.67	.666	.234	35.2
Dec. 7	118.6	12.7	7.76	107.0	10.34	7.25	.582	.196	33.6
Dec. 9	128.3	12.3	7.51	108.0	11.18	9.42	.614	.257	41.8
Dec. 10	143.1	13.3	7.65	111.6	12.47	10.65	.786	.300	38.2
Dec. 9	135.8	13.0	7.57	115.4	11.84	10.09	.679	.294	43.3
Dec. 11	74.7	13.9	7.62	166.9	6.51	4.24	.454	.179	39.4

Diameter of working cylinder . . . . . 6.75″
Stroke of working cylinder . . . . . 9.53″
Diameter of compression cylinder . . . . . 6.75″
Stroke of compression cylinder . . . . . 8.59″

TESTS ON AN ERICSSON HOT AIR ENGINE.

Date.	Revolutions per minute.	M. E. P.	Capacity. (Gallons per minute.)	Total lift.	Horse power indicated.	Horse power by pump.	Mechanical Efficiency.
1896.							
Dec. 1	100.8	4.56	5.53	44.3	.229	.062	27.0
Nov 24	93.9	4.30	4.97	47.9	.201	.060	30.0
Dec. 2	110.6	4.95	6.14	51.7	.272	.080	29.4

Diameter of cylinder . . . . . 8″
Stroke of piston . . . . . 3.92″

TESTS ON THE FLOW OF STEAM.

Experiments on the Flow of Steam Through an Orifice $\frac{1}{2}''$ in Diameter.

Date.	Boiler pressure.	Back pressure.	Barometer pressure.	Weight of condensed steam.	Steam per hour by experiment.	By Napier's formula.	Coefficient of flow by Napier's equation.	Ratio of absolute back pressure to absolute boiler pressure.
1896.								
Mar. 11	112.4	15.0	14.5	971.5	1,296	1,281	1.012	.2325
Dec. 2	70.3	7.8	14.8	391.5	870	859	1.013	.2656
Dec. 9	72.27	9.83	14.3	445.2	890	874	1.018	.2783
Dec. 9	71.59	10.96	14.3	353	883	867	1.019	.2934
Mar. 12	111.9	23.4	14.5	966	1,288	1,276	1.009	.2998
Mar. 12	111.4	23.4	14.5	968.5	1,291	1,272	1.015	.3009
Nov. 9	68.20	10.77	14.5	56	844	835	1.012	.3060
Nov. 4	51.9	8 5	14.7	343	686	672	1.021	.3483
Oct. 28	49.3	7.8	14.8	330	661	647	1.022	.3526
Oct. 21	51.7	9.15	14.6	339	678	669	1.014	.3575
Mar. 2	109.6	35.6	14.6	955	1,273.5	1,254	1.016	.4042
Mar. 4	111.9	38.2	14.6	975	1,300	1,277	1.017	.4174
Oct. 28	51.4	14.0	14.7	238	680	667	1.020	.4327
Mar. 15	93.8	35.2	14.7	560	1,120	1,095	1.023	.4550
Feb. 11	95.7	37.2	14.7	567	1,134	1,115	1.017	.4701
Feb. 12	94.8	40.2	14.6	563	1,126	1,105	1.019	.5008
Feb. 19	101.0	44.8	14.5	896	1,195	1,168	1.024	.5135
Nov. 4	48.23	18.07	14.7	324	649	635	1.022	.5214
Oct. 27	48.66	20.03	14.6	328	657	639	1.028	.5467
Nov. 4	49.2	21.1	14.7	330	661	645	1.024	.5603
Mar. 15	111.3	56.7	14.6	129.0	1,290	1,272	1.015	.5662
Feb. 23	91.6	48.4	14.4	821	1,095	1,070	1.023	.5926
Mar. 8	111.7	51.7	14.8	975	1,300	1,277	1.017	.6047
Feb. 24	100.4	55.3	14.6	592	1,184	1,161	1.020	.6081
Oct. 19	50.8	27.3	14.5	669	669	646	1.035	.6400
Dec. 9	70.27	44.52	14.3	330	826	801	1.031	.6958
Oct. 28	51.0	33.0	14.7	313	626	603	1.038	.7259
Oct. 21	51.9	33.8	14.5	324	648	609	1.064	.7273
Oct. 28	41.1	26.5	14.8	267	535	506	1.058	.7391
Dec. 2	64.7	44.1	14.8	380	760	718	1.059	.7408
Nov. 18	71.67	50.89	14.6	403	806	760	1.059	.7590
Oct. 21	52.1	37.2	14.6	306	613	572	1.070	.7766
Nov. 18	73.95	63.94	14.6	314	628	580	1.082	.8861

The apparatus used was made of 3″ pipe arranged as shown by the cut on page 359 of *Technology Quarterly*, Vol. V, No. 4, December, 1892.

RESULTS OF TESTS ON A 9″–24″ x 30″ COMPOUND ENGINE.

				Water by Jackets.						
Number.	Horse power.	Steam per horse power per hour.	Steam through cylinders per hour.	High jacket.	Second receiver jacket.	Low jacket.	Revolutions per minute.	Boiler pressure by gauge.	Vacuum in condenser. (Inches of mercury.)	Barometer. (Ins.)
1	69.11	19.31	1,334	....	....	....	80.87	105.8	26.5	28.88
2	75.33	19.56	1,477	....	....	....	80.25	105.8	26.5	29.84
3	77.49	19.42	1,512	....	....	....	80.22	105.8	26.2	29.20
4	51.87	19.95	1,035	....	....	....	82.72	119.3	24.7	29.56
5	54.89	19.34	1,061	....	....	....	83.25	119.6	25.4	29.80
6	57.00	19.27	1,098	....	....	....	82.75	119.6	24.9	29.50
7	63.89	18.49	1,181	....	....	....	81.88	119.2	26.0	29.50
8	65.36	18.30	1,196	....	....	....	81.62	119.6	25.4	29.48
9	66.24	18.07	1,197	....	....	....	82.40	121.0	26.4	29.32
10	70.02	18.17	1,272	....	....	....	81.75	119.3	26.1	29.46
11	71.27	18.14	1,293	....	....	....	81.30	119.2	25.1	29.61
12	81.41	17.46	1,421	....	....	....	81.28	123.9	26.4	29.95
13	81.78	17.62	1,443	....	....	....	81.00	125.5	26.3	29.74
14	82.92	17.40	1,469	....	....	....	81.38	124.8	26.5	29.63
15	87.07	18.01	1,568	....	....	....	80.89	119.6	24.7	29.62
16	69.2	17.24	1,016	....	....	177.1	82.83	120.6	26.3	30.17
17	72.08	16.11	1,006	....	....	155.1	82.90	120.7	26.3	30.00
18	72.61	16.21	1,019	....	....	163.4	83.20	118.9	26.9	29.40
19	93.68	16.24	1,354	....	....	167.3	81.48	119.2	26.0	29.50
20	98.32	16.73	1,436	....	....	208.6	81.12	119.5	26.3	29.39
21	73.14	16.16	990	46.0	....	145.7	82.57	119.2	25.7	29.32
22	63.07	15.96	844.5	42.0	37.5	82.8	82.73	100.2	26.6	29.49
23	63.19	15.59	820.0	39.2	51.5	74.5	82.90	101.0	26.6	29.49
24	78.13	16.16	1,059.0	42.6	72.8	88.5	81.72	100.9	26.3	29.49
25	80.47	16.14	1,086.0	44.2	80.1	87.9	81.37	101.4	26.3	29.49

RESULTS OF TESTS ON A 9″–24″ x 30″ COMPOUND ENGINE — *Continued.*

HIGH.

Number.	Initial pressure.	Per cent. of cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in cylinder at cut-off.	Per cent. of steam in cylinder at release.	M. E. P. crank end.	M. E. P. head end.	Horse power.
1	94.6	32.6	86.4	26.2	3.8	70.92	77.51	60.9	57.0	44.45
2	94.6	39.0	89.8	32.2	7.3	76.11	79.61	64.5	61.1	47.00
3	94.0	40.8	87.2	33.5	6.8	74.76	79.45	62.8	63.5	47.04
4	117.0	14.4	105.3	15.1	2.0	60.46	72.14	53.1	43.1	37.02
5	117.8	13 7	110.0	15.5	1.2	61.08	75.58	52.6	49.5	39.63
6	117.4	16.1	108.9	17.0	1.9	62.28	75.76	53.5	51.3	40.46
7	117.5	20.0	108.0	21.1	3.4	66.55	77.24	58.8	55.6	43.68
8	116.1	21.5	112.2	23.0	3.8	71.03	80.90	61.1	56.3	44.66
9	118.1	20.4	111.1	21.4	2.6	70.02	78.33	59.4	59.3	45.65
10	117.8	23.0	107.1	25.1	3.2	67.97	80.63	64.9	59.8	47.52
11	118.5	24.7	114.3	26.7	4.7	73.60	81.63	64.3	62.0	47.88
12	121.6	28.4	113.8	30.9	8.1	74.83	81.00	69.5	68.9	52.50
13	121.8	28.1	114.5	30.1	7.5	76.37	78.39	70.0	66.9	51.71
14	122.0	30.0	110.9	31.3	6.7	74.40	79.20	71.6	69.8	53.68
15	118.0	33.5	108.8	36.1	3.4	73.85	82.05	76.6	74.3	56.92
16	118.4	15.2	110.4	16.7	8.4	65.97	79.59	44.9	44.4	34.51
17	117.9	14.5	110.7	16.3	7.2	65.88	80.44	47.2	46.5	36.25
18	116.4	15.0	107.7	15.8	7.4	64.78	77.18	46.3	42.9	34.60
19	115,3	25.6	108.3	27.6	3.0	69.79	80.42	68.0	64.9	50.49
20	116.9	29.9	110.1	31.5	4.1	74.71	81.95	71.3	69.4	53.24
21	117.9	15.8	113.2	18.3	5.4	69.58	85.10	53.5	46.8	38,58
22	96.5	16.3	92.3	12.8	3.0	70.18	83.98	43.4	37.9	31.41
23	97.9	15.6	94.1	12.6	4.1	71.11	85.59	42.2	37.5	30.77
24	97.4	24.0	93.0	20.6	4.5	73.60	84.97	52.2	49.2	38.63
25	98.3	25.4	93.7	21.4	5.5	76.24	83.73	53.2	50.4	39.30

RESULTS OF TESTS ON A 9″–24″ x 30″ COMPOUND ENGINE — *Concluded.*

	Low.												
Number.	Initial pressure.	Per cent. of cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in cylinder at cut-off.	Per cent. of steam in cylinder at release.	M. E. P. crank end.	M. E. P. head end.	Horse power.	B. T. U. per horse power per minute actual.	B. T. U. per horse power per minute reduced to 2 lbs. absolute.
1	+0.9	11.5	—0.9	—10.3	—11.4	43.59	64.40	4.44	4.13	24 66	354.6	372.2
2	+3.5	11.5	+0.8	—10.2	—11.6	42.20	65.61	5.30	4.98	28.33	356.3	361.9
3	+4.2	12.2	1.1	— 9.9	—11.3	45.14	63.48	5.92	5.14	30.45	355.5	362.4
4	—1.8	10.7	—4.0	—10.7	—10.8	41.38	78.68	2.75	2.48	14.85	358.8	345.7
5	—2.7	13.7	—5.2	—11.3	—11.4	40.49	68.25	2.90	2.44	15.26	349.3	346.3
6	—1.5	11.0	—3.6	—11.1	—11.6	42.89	66.42	3.03	2.79	16.54	347.1	338.5
7	—0.1	11.7	—4.0	—11.2	—12.0	39.17	62.32	3.97	3.22	20.21	336.7	343.4
8	+0.5	11.0	—3.1	—10.7	—11.7	39.91	69.97	4 05	3.34	20.70	331.1	331.1
9	—1.3	14.0	—4.4	—10.8	—11.9	41.17	67.19	3.80	3.48	20.59	331.2	344.7
10	0.0	13.7	—3.7	—10.8	—11.8	40.45	64.62	4.18	3.84	22.50	331.0	336.7
11	+2.2	11.0	—2.0	—10.6	—11.5	40.41	66.18	4.58	3.80	23.39	327.2	333.4
12	+3.4	14.0	—1.2	—10.3	—11.7	45.26	67.20	5.35	5.01	28.91	317.4	321.5
13	+3.8	14.0	—0.8	—10.3	—11.7	41.85	66.15	5.53	5.27	30 07	320 5	323.3
14	+3 3	14.0	—1.4	—10.2	—11.5	43.01	64.27	5.59	4.88	29.24	323.0	328.9
15	+1.3	20.0	—1.4	— 9.8	—10.7	48.69	64.71	5.43	5.16	30.15	323.9	317.6
16	+4.9	15.0	+1.0	—10.3	—11.7	76.44	95.41	6.37	5.83	34.69	302.8	304.8
17	+2.2	21.0	—1.6	—11.7	—12.3	80.44	79.80	6.58	6.01	35.83	284.3	308.6
18	+4.2	17.0	—0.3	—10.7	—12.2	78.99	81.75	6.93	6.38	38.01	289.2	304.4
19	+1.2	35.7	—2.0	— 9.4	—11.6	81.21	82.35	7.74	7.70	43.19	288.8	292.5
20	+2.2	36.3	—1.5	— 8.9	—11.6	79.97	85.00	8.00	8.18	45.08	297.5	303.1
21	+2.4	21.5	—1.2	—10.6	—11.6	69.79	84.05	6.37	5.82	34.56	285.7	289.0
22	+1.5	18.0	—0.5	—11.1	—12 4	91.94	87.62	5.95	5.17	31.66	282.1	294.7
23	+1'8	18.0	—0.3	—11.2	—12.3	95.20	88.19	6.01	5.38	32.42	275.1	287.4
24	+2.8	24.7	—0.1	—10.2	—12.0	92.13	88.57	7.38	6.70	39.50	284.4	290.4
25	+3.5	24.7	+0.5	—10.2	—12.0	92.58	87.86	7.65	7.09	41.17	283.8	289.7

TESTS ON HANCOCK LOCOMOTIVE INSPIRATOR NO. 4, C.

Number of test.	Duration. (Minutes.)	Lift. (Feet.)	Boiler pressure. (Lbs. per sq. in.)	Delivery pressure. (Lbs. per sq. in.)	Barometer. (Lbs. per sq. in.)	Suction temperature. C°.	Delivery temperature. C°.	Water pumped. (Lbs. per hour.)	Water delivered. (Lbs. per hour.)	Steam used. (Lbs. per hour.)	Water delivered. (Per lb. of steam.)	Delivery capacity. (Gals. per hour.)
71	30	3.94	90.7	99.6	14.4	5.8	55.8	6,420	6,958	538	12.9	846
75	30	4.02	95.6	99.6	14.6	13.3	64.9	6,430	6,984	554	12.6	853
76	30	4.01	100.6	106.0	14.5	5.8	58.4	6,642	7,226	584	12.4	870
77	30	4.01	100.6	110.0	14.6	6.1	58.7	6,676	7,276	600	12.1	886
78	30	4.03	101.7	114.0	14.5	6.2	59.2	6,652	7,240	588	12.3	882
79	30	4.01	105.2	116.2	14.8	5.5	59.2	6,759	7,365	606	12.1	897
80	30	4.03	105.6	112.0	14.2	11.0	65.1	6,581	7,181	600	12.0	878
81	30	4.04	109.9	113.2	14.7	5.7	60.7	6,840	7,456	616	12.1	909
83	30	4.04	110.5	118.8	14.5	7.4	62.4	6,781	7,424	643	11.6	905
84	30	4.05	110.5	119.3	14.5	14.0	69.3	6,676	7,312	636	11.5	896
86	29	4.04	110.6	119.0	14.7	6.6	61.3	6,829	7,465	636	11.7	910
87	30	4.02	110.6	120.5	14.5	11.9	66.5	6,743	7,382	639	11.5	903
88	30	4.03	110.6	120.5	14.5	10.5	65.3	6,746	7,392	646	11.4	903
89	30	4.02	110.6	120.5	14.5	9.9	64.8	6,474	7,408	634	11.7	905
90	30	4.02	110.7	118.7	14.8	9.4	64.1	6,804	7,444	640	11.6	909
91	30	4.02	110.7	118.8	14.8	9.8	64.7	6,812	7,459	647	11.5	911
94	30	4.03	115.2	123.8	14.3	6.1	62.4	6,891	7,538	648	11.7	919
95	30	4.04	115.6	128.7	14.6	14.2	69.8	6,796	7,431	635	11.7	910
96	30	4.02	115.6	123.0	14.7	11.4	67.4	6,856	7,522	666	11.3	921
97	30	4.02	115.6	124.9	14.6	9.0	65.2	6,885	7,567	682	11.1	924
99	30	4.04	115.7	125.0	14.3	7.1	63.6	6,892	7,552	660	11.4	922
101	30	4.02	115.7	127.6	14.7	9.3	65.3	6,908	7,584	676	11.2	927
102	30	4.03	115.7	125.4	14.7	9.9	65.8	6,874	7,538	664	11.4	921
103	30	4.01	115.8	124.7	14.2	7.2	63.3	6,840	7,504	664	11.3	916
107	30	4.02	115.8	126.9	14.7	8.9	65.1	6,914	7,587	673	11.0	927
108	30	4.02	115.9	125.9	14.5	9.9	66.0	6,862	7,521	659	11.4	919
109	30	4.03	116.0	125.7	14.6	6.2	62.6	6,923	7,589	666	11.4	926

Hirn's Analysis Applied to a Receiver Jacketed Cross Compound Engine.

By the application of Hirn's analysis to an engine, the interchange of heat between the steam and the walls of the cylinder can be calculated for different parts of the stroke.

To carry on such a test, it is necessary to make what may be called a heat balance test. This requires, in addition to the observations usu-

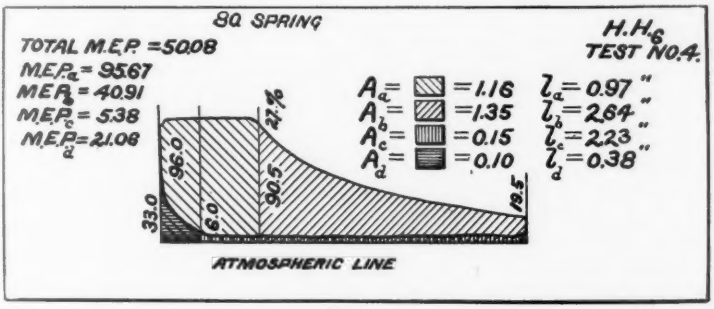


Fig. 1.

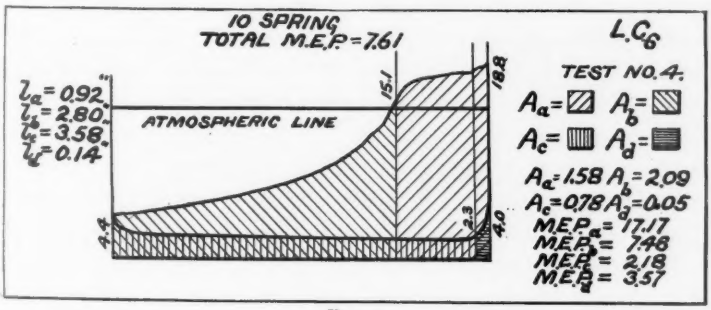


Fig. 2.

ally taken for simple engine tests, a knowledge of the quality of the steam entering the cylinder, the weight and gain in temperature of the condensing water, and the weight and temperature of the condensed steam leaving the condenser. The work as shown by the indicator cards is broken up into four parts, that during admission, during exhaust, during expansion, and during compression.

Figures 1 and 2 represent cards taken during test No. 4; Figure 1 from the head end of the high-pressure cylinder, and Figure 2 from

the crank end of the low-pressure cylinder. The different cross-hatchings show the areas which have to be planimetered in order to calculate the work for these several parts of the stroke.

The heat equivalents of the work done per stroke during admission, expansion, exhaust, and compression are represented by $A\ W_a$, $A\ W_b$, $A\ W_c$, and $A\ W_d$ respectively, where W represents the foot-pounds of work done, and A is the heat equivalent of 1 foot-pound, or $\frac{1}{778}$ B. T. U. In calculating the different values of W for the high-pressure cylinder cards, the mean effective pressures above the absolute zero must be used. It is more convenient to add the pressure of the atmosphere in pounds to the M. E. P. calculated above the atmospheric line, than to draw in the absolute zero line, as has been done on the low-pressure cards.

The following equations are made use of in the calculations. These equations are quoted from an article printed in the *Technology Quarterly*, Vol. IV, No. 3, October, 1891, by Professor C. H. Peabody.

The heat taken inside the cylinder per stroke is $M\ (xr + q)$, M being the weight of condensed steam per stroke, x being the quality of the entering steam (or 1 — priming), q and r the heat of the liquid and the total latent heat respectively. at the absolute steam pressure at the throttle. The heats Q_J, Q_{JR}, and Q'_J, supplied by the jackets on the high-pressure cylinder, intermediate receiver, and low-pressure cylinder, are calculated by multiplying the weight per stroke condensed in each by $x\,r$; the engine being jacketed with full boiler pressure. The heats Q_e, Q_{eR}, and Q'_e, lost from the jackets by radiation to the air, are figured from the rates of condensation in the jackets noted immediately after stopping the engine.

The heat equivalent of the intrinsic energy of the mixture in the cylinder at the different points of the stroke is

at beginning of admission,	$I_0 = M_0\ (q_0 + x_0\ \rho_0)$
at cut-off	$I_1 = (M + M_0)\ (q_1 + x_1\ \rho_1)$
at release	$I_2 = (M + M_0)\ (q_2 + x_2\ \rho_2)$
at compression	$I_3 = M_3\ (q_3 + x_3\ \rho_3)$

where M_0 is the average weight of steam in the cylinder at compression or admission, figured by assuming the steam to be dry at compression.

The different values of q and ρ, the heat of the liquid and the internal latent heat, are taken at the average absolute pressure measured at the proper points on a pair of cards.

The per cent. of the weight of mixture present accounted for as steam at cut-off or at release, denoted by x_1 or x_2, is found as follows: The average volume at cut-off is $V_1 + V_0$ where V_1 is the mean piston displacement up to cut-off and V_0 is the average clearance. This volume is occupied by $(M + M_0)$ pounds of the mixture of steam and water. The volume of one pound of a mixture is $x\,s + (1 - x)\,\frac{1}{62.4}$ where s is the volume of a pound of steam. This may be reduced to $x\,(s - .016) + .016$, or $x\,u + .016$.

Then $(M + M_0)\,(x_1\,u_1 + .016) = V_1 + V_0$ from which x_1 can be calculated. The value u_1 or $(s_1 - .016)$ is taken from the tables at the mean absolute pressure at cut-off. x_0 and x_3 are assumed to be unity. A considerable error in this assumption would affect the results but slightly. The heat carried away per stroke by the condensed steam and the condensing water is $Mq_4 + G\,(q_k - q_i)$; where q_4, q_k and q_i are the heats of the liquid corresponding to the temperatures of the condensed steam, the hot and the cold condensing water, and where G is the weight of cooling water per stroke.

The accuracy of the test may be checked by noting the agreement between the radiation loss as determined by experiment, and the heat unaccounted for by the following equation: "Heat unaccounted for" $= Q + Q_J + Q_{JR} + Q'_J - Mq_4 - G\,(q_k - q_i) - A\,W_{high} - A\,W_{low}$.

In all tests excepting No. 4 this agreement is very good.

The interchanges of heat for the high-pressure cylinder may be written as follows:

during admission $\quad Q_a = Q + I_0 - I_1 - A\,W_a$

during expansion $\quad Q_b = I_1 - I_2 - A\,W_b$

during exhaust $\quad Q_c = I_2 - I_3 - Q - Q_J + Q_e + A\,W_{high} + A\,W_c$

during compression $\quad Q_d = I_3 - I_0 + A\,W_d$.

It is evident if there was no interchange during admission that $Q + I_0 = I_1 + A\,W_a$. On account of the interchange, the term Q_a, necessary to balance the two sides, may be given either a positive or a negative sign. As applied in these equations, the positive sign indicates heat given up by the walls, and the negative sign heat absorbed by the walls.

In the equation for Q_e, the interchange during exhaust, the expression $-(Q + Q_J - Q_e - AW_{high})$ represents the heat carried away by the exhaust.

The interchanges of heat for the low-pressure cylinder are:

during admission $Q'_a = Q + Q_J - Q_e - AW_{high} + Q_{JR} - Q_{eR} + I'_0 - I'_1 - AW'_a$

during expansion $Q'_b = I'_1 - I'_2 - AW'_b$

during exhaust $Q'_c = I'_2 - I'_3 - Mq_4 - G(q_k - q_i) + AW'_c$

during compression $Q'_d = I'_3 - I'_0 + AW'_d$.

The following tests were conducted and calculated by the students as a part of the regular work of the Engineering Laboratories.

CRANKS SET WITH LOW LEADING THE HIGH BY 120°.

High-Pressure Cylinder.

Dia. of piston = 8.99″. Dia. of piston rod = 2.19″. Stroke = 30″.
Piston displacement: H. E. = 1.102 cu. ft.; C. E. = 1.037 cu. ft.
Clearance in % of P. D.: H. E. = 8.83; C. E. = 9.76.
Engine constant: H. E. = .004809; C. E. = .004524.

Low-Pressure Cylinder.

Dia. of piston = 24.063″. Dia. of piston rod = 2.16″. Stroke 30″.
Piston displacement: H. E. = 7.894 cu. ft.; C. E. = 7.831 cu. ft.
Clearance in % P. D.: H. E. = 12.18; C. E. = 12.27.
Engine constant: H. E. = .0345; C. E. = .03417.

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Test Number.	I.	II.	III.	IV.
Duration of test, minutes	60	60	60	60
Total number of revolutions	4,976	4,974	4,903	4,882
Revolutions per minute	82.93	82.90	81.72	81.37
Steam consumption during test, pounds:				
Passing through cylinders	844.5	820.0	1059.0	1086.0
Condensation in h. p. jacket	42.0	39.0	42.5	44.0
" in receiver jacket	37.5	51.5	73.0	80.0
" in l. p. jacket	82.8	74.5	88.5	88.0
Total	1006.8	985.0	1263.0	1298.0
Condensing water for test, pounds	16,066	16,287	21,800	21,960
Priming, by calorimeter	1.0%	0.9%	1.13%	0.9%
Temperatures, Fahrenheit:				
Condensed steam	93.4	91.4	86.0	89.2
Condensing water, cold	52.2	52.2	52.5	52.7
Condensing water, hot	105.8	104.2	102.6	104.0
Pressure of the atmosphere, by the barometer, pounds per square inch	14.5	14.5	14.5	14.5
Boiler pressure, pounds per square inch, absolute	114.7	115.5	115.4	115.9
Vacuum in condenser, inches of mercury	26.6	26.6	26.3	26.3
Events of the stroke, per cent.:				
High-pressure cylinder —				
Cut-off, crank end	16.8	15.8	23.8	25.2
head end	15.7	15.4	24.2	25.6
Release, both ends	100	100.0	100.0	100.0
Compression, crank end	7.5	7.5	7.5	7.5
head end	11.5	11.5	10.5	10.5
Low-pressure cylinder —				
Cut-off, crank end	18.0	18.0	24.5	24.5
head end	18.0	18.0	25.0	25.0
Release, both ends	100.0	100.0	100.0	100.0
Compression, crank end	3.5	3.5	3.5	3.5
head end	5.5	5.5	4.0	4.0
Absolute pressures in the cylinder, pounds per square inch:				
High-pressure cylinder —				
Cut-off, crank end	106.5	109.5	107.5	108.3
head end	107.1	107.7	107.5	108.1
Release, crank end	29.9	29.5	37.0	38.2
head end	24.7	24.8	33.2	33.7
Compression, crank end	17.2	17.7	18.0	18.7
head end	17.8	19.5	20.1	21.3
Admission, crank end	32.7	35.5	36.5	38.2
head end	42.2	42.5	45.2	46.9

Test Number.	I.	II.	III.	IV.
Low-pressure cylinder —				
Cut-off, crank end	14.4	14.5	14.7	15.1
head end	13.6	13.9	14.2	14.9
Release, crank end	3.4	3.3	4.2	4.2
head end	3.3	3.3	4.4	4.5
Compression, crank end	1.9	2.0	2.2	2.2
head end	2.4	2.5	2.8	2.9
Admission, crank end	3.4	3.5	4.1	3.7
head end	4.4	4.7	5.8	4.9
Heat equivalents of external work, B. T. U. from areas on indicator diagram to line of absolute vacuum:				
High-pressure cylinder —				
During admission, AW_a, crank end	3.59	3.38	5.13	5.45
head end	3.49	3.47	5.43	5.83
During expansion, AW_b, crank end	7.94	8.05	8.38	8.43
head end	7.81	7.97	8.48	8.57
During exhaust, AW_c, crank end	2.86	2.96	3.11	3.28
head end	2.91	3.03	3.18	3.54
During compres'n, AW_d, crank end	0.35	0.37	0.38	0.40
head end	0.67	0.72	0.72	0.72
Low-pressure cylinder —				
During admission, AW_a, crank end	4.13	4.15	5.93	6.11
head end	4.07	4.13	5.99	6.25
During expansion, AW_b, crank end	7.19	7.25	7.78	7.99
head end	7.05	7.12	7.88	8.16
During exhaust, AW_c, crank end	2.64	2.55	2 87	2.98
head end	3.25	3.10	3.98	4.00
During compres'n, AW_d, crank end	0.12	0 13	0.17	0.17
head end	0.33	0 32	0.28	0 29
Quality of the steam in the cylinder. At admission and at compression the steam was assumed to be dry and saturated:				
High-pressure cylinder —				
At cut-off x_1	70.18	71.11	73.60	76.24
At release x_2	83.98	85.59	84.97	83.73
Low-pressure cylinder —				
At cut-off x_1	91.94	95.20	92.13	92.58
At release x_2	87.62	88.19	88.57	87.86

Test Number.	I.	II.	III.	IV.
Interchanges of heat between the steam and the walls of the cylinders, in B. T. U. Quantities affected by the positive sign are absorbed by the cylinder walls; quantities affected by the negative sign are yielded by the walls:				
High-pressure cylinder —				
Brought in by steam . Q	99.82	97.10	126.90	131.30
During admission . . Q_a	25.22	23.85	27.14	25.83
During expansion . . Q_b	—15.01	—15.84	—16.13	—12.60
During exhaust . . . Q_c	—11.13	—10.04	—12.99	—15.47
During compression . Q_d	0.98	0.45	0.46	0.47
Supplied by jacket . . Q_f	3.70	3.45	3.81	3.97
Lost by radiation . . Q_e	1.87	1.87	2.20	2.20
Second intermediate receiver —				
Supplied by jacket . . Q'_{fR}	3.30	4.53	6.50	7.19
Lost by radiation . . Q'_{eR}	0.69	0.69	1.60	1.60
Low-pressure cylinder —				
Brought in by steam . Q''	96.24	94.26	123.40	128.53
During admission . . Q''_a	7.63	5.44	9.63	10.57
During expansion . . Q''_b	— 1.75	— 1.12	— 2.03	— 0.97
During exhaust . . . Q''_c	—11.11	— 7.53	— 9.92	—16.53
During compression . Q''_d	0.33	2.21	0.11	0.64
Supplied by jacket . . Q''_f	7.30	6.56	7.91	7.85
Lost by radiation . . Q''_e	4.44	4.44	5.70	5.70
Total loss by radiation:				
By preliminary test . . ΣQ_e	7.39	7.39	9.52	9.52
By equation	7.00	5.78	7.83	4.42
Power and economy:				
Heat equivalents of works per stroke:				
High-pressure cylinder . AW . .	8.02	7.89	10.01	10 17
Low-pressure cylinder . AW'' . .	8.10	8.27	10.04	10.53
Totals	16.12	16.16	20.05	20.70
Total heat furnished by jackets . . .	14.30	14.54	18.22	19.01
Distribution of work:				
High-pressure cylinder	1.00	1.00	1.00	1.00
Low-pressure cylinder	1.01	1.05	1.00	1.04
Total horse-power	63.07	63.19	78.13	80 47
Steam per horse-power per hour . . .	15.96	15.59	16 16	16.14
B. T. U. per horse-power per minute .	282.1	275.1	284.4	283.8
B. T. U. per horse-power per minute, 2 pounds absolute	294.7	287.4	290.4	289.7

TESTS ON DUPLEX PUMP AT MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

Date.	Single strokes per minute.	Length of stroke. (West.)	Length of stroke. (East.)	Steam pressure by gauge.	Weight of condensed steam per hour. (Lbs.)	Total head. (Feet.)	M. E. P. Steam Cylinders.				Horse-power. (Steam cylinders.)	Horse-power. (Output.)	Efficiency. (Per cent.)	Apparent capacity of pump. (Gallons.)	Capacity of pump by gallons.	Steam per horse-power per hour.	B. T. U. per horse-power per minute.	Duty. (Foot-pounds per 1,000,000 B. T. U.)
							West. (Head end.)	West. (Pump end.)	East. (Head end.)	East. (Pump end.)								
Nov. 10, 1896	181.3	11.4	11.2	40.6	2,544	162.3	33.30	30.88	34.50	33.25	34.03	28.6	84 0	753	698	74.8	1,237	22,400,000
Nov. 11, 1896	186.2	10.87	10.98	40.5	2,599	163.10	33.29	32.10	31.88	32.39	33.26	28.57	86	750	694	78.1	1,288	22,010,000
Nov. 11, 1896	190.6	11.11	11.79	45.3	2,781	184.7	37.2	37.7	36.8	38.1	41.2	34.7	84.3	803	745	67.6	1,117	24,910,000
Nov. 12, 1896	194.1	11.07	11.29	44.9	2,802	183.6	36.9	37.4	36.3	37.4	40.5	34.4	84.89	843	742	69.2	1,145	24,540,000
Nov. 16, 1896	108.8	11.19	11	49.11	1,978	229.9	45.03	45.02	46.09	45.5	27.6	23.2	84	444	787	71.6	1,176	23,590,000
Nov. 19, 1896	215.9	10.4	10.2	46.1	2,891	177.8	39.24	37 21	37.60	37.71	42.5	34.2	80.4	819	761	67.9	1,123	23,620,000
Nov. 20, 1896	191.2	10.6	10.5	34.9	2,275	154.5	32.3	29	29.8	28.9	30.4	26.7	87.9	742	687	74.8	1,231	23,570,000
Nov. 23, 1896	185.8	10.7	10.2	35.0	2,368	147.1	31.01	27.19	29.73	27 72	28.4	24.8	87.3	715	668	83.4	1,314	21,940,000
Nov. 30, 1896	106	11.78	11.86	53.4	2,008	261.7	49.60	45.5	47.7	49.1	30.3	26.8	88.6	463	406	66.3	1,097	26,660,000
Nov. 30, 1896	188.3	10.75	10.82	36.42	2,355	156	31.91	27.75	30.26	29.60	30.5	27.6	90.6	748	702	77.1	1,271	23,540,000
Dec. 2, 1896	190.5	11.15	11.05	40.8	2,718.8	172.9	34.68	34.25	34.59	31.61	35.8	32.1	89.8	778	737	75.9	1,251	23,440,000
Dec. 2, 1896	193.7	11.11	11.02	40.5	2,588.3	174.5	35.7	32.6	34.8	33.0	36.8	32.8	89.1	787	745	70.4	1,160	25,380,000
Dec. 3, 1896	221.0	10.7	10.5	50	3,210	204.3	42.2	40.0	41.5	38.6	47.9	41.3	86.2	862	801	67.02	1,109	25,670,000
Dec. 4, 1896	101.6	11.6	11.2	45.56	1,719	228.9	43.4	42.5	43.0	42.6	24.8	21.8	88.0	426	378	69.29	1,145	25,390,000
Dec. 4, 1896	94.5	11.5	11.5	40.11	1,506	204.9	38.31	37.41	36.80	37.52	20.6	18.2	88.5	400	352	73.1	1,204	24,240,000
Dec. 7, 1896	187.7	11.4	11.25	40.53	2,549.3	172.9	34 51	33.94	33.49	32.57	36.1	32.3	89.5	783	741	70.60	1,163	25,390,000
Dec. 9, 1896	152.1	11.11	10.93	25.0	1,583	116.2	21.8	21 1	22.0	21.6	18.2	17.2	94.5	617	586	86.98	1,425	21,870,000
Dec. 9, 1896	162	11.5	11.1	30.01	1,966	132.1	25.5	25.3	26.0	24.6	23.3	21.1	90.6	674	633	84.3	1,385	21,590,000
Dec. 10, 1896	152.0	11.12	11.01	24.91	1,617	115.2	22.67	21.57	22.24	21.93	18.8	16.8	89.4	619	578	108.2	1,408	20,950,000

TESTS ON PULSOMETER.

Date.	Total lift. (Feet.)	Steam pressure at pulsometer. (Gauge.)	Steam used per hour. (Pounds.)	Water pumped per hour including steam.	Temperature at suction. °C.	Temperature at discharge. °C.	Work done by pulsometer. (Foot-pounds.)	Total heat given up by steam. (B. T. U.)	Efficiency. (Per cent.)	Duty, foot-pounds per 1,000,000 B. T. U. (Delivery.)	Duty, foot-pounds per 1,000,000 B. T. U. (Suction.)	Capacity. (Gallons per minute.)
1896.												
Oct. 5	28.56	26.5	294.9	37,310	27.5	32.5	1,063,000	326,000	.42	3,262,000	3,229,000	74.6
Oct. 6	30.43	30.54	380.6	42,880	30.3	35.8	1,302,000	419,100	.40	3,107,000	3,079,000	85.8
Oct. 7	29.74	30.6	370.2	42,770	27.1	32.2	1,269,000	410,000	.39	3,095,000	3,070,000	91.7
Oct. 8	31.07	31.0	370.7	45,360	28.1	33.2	1,406,000	410,000	.44	3,429,000	3,402,000	90.8
Oct. 12	31.32	30.4	359.0	46,380	24.94	29.76	1,449,000	399,200	.48	3,631,000	3,594,000	92 8
Oct. 13	30.20	32.3	370.6	42,970	27.19	32.62	1,303,000	410,600	.41	3,173,000	3,140,000	86 o
Oct. 14	30.43	30.4	369.0	42,740	28.8	34.1	1,298,000	407,000	.41	3,186,000	3,159,000	85.5
Oct. 14	31.26	27.8	380.9	43,610	29.0	34.6	1,360,000	419,800	.42	3,240,000	3,210,000	87.3
Oct. 15	30.18	21.8	431.4	42,270	29.3	34.8	1,272,000	474,200	.34	2,682,000	2,659,000	84.6
Oct. 19	23.18	29.0	241.5	31,540	24.4	29.0	729,500	268,700	.35	2,714,000	2,695,000	63.1
Oct. 21	23.97	26.6	244.5	31,270	25.3	30.2	748,000	271,100	.35	2,758,000	2,736,000	62.6
Oct. 21	23.25	22.6	241.0	29,810	27.8	32.5	691,400	266,100	.33	2,598,000	2,579,000	59.6
Oct. 22	24.99	21.6	251.7	31,550	25.5	30,3	785,800	278,500	.36	2,821,000	2,799,000	63.1
Oct. 26	24.84	26.9	234.6	29,770	23 2	28 2	737,300	261,000	.36	2,825,000	2,802,000	59.6
Oct. 26	24.59	23.7	254.4	33,470	26.1	30.8	821,000	283,900	.37	2,892,000	2,909,000	66.9
Oct. 27	24.18	30.1	239.4	30,980	26.3	31.1	746,200	266,000	.36	2,805,000	2,789,000	62.0
Oct. 28	23.89	29.3	236.2	30,060	26.8	31.6	716,400	261,700	.35	2,737,000	2,715,000	60.1
Oct. 28	22.76	24.1	201.8	28,860	26.2	29.2	655,300	224,100	.38	2,922,000	2,909,000	57.7
Oct. 29	23.91	24.6	244.1	33,330	27.2	31.5	795,300	270,400	.38	2,943,000	2,926,000	66.7
Nov. 2	25.75	28.6	241.7	34,530	25.2	28.6	887,100	271,300	.42	3,269,000	3,295,000	69.1
Nov. 2	25.01	27.7	231.2	32,310	27.3	31.7	800,100	258,000	.40	3,128,000	3,104,000	64.6
Nov. 3	22.92	29.0	228.8	30,400	31.9	27.5	695,100	255,100	.35	2,744,000	2,726,000	60.8
Nov. 4	24.35	22 4	244.2	32,920	25.9	30.4	799,400	272,200	.38	2,956,000	2,937,000	65.9
Nov. 4	24.57	28.0	242.4	32,630	27.6	32.1	800,300	270,200	.38	2,984,000	2,962,000	65.3
Nov. 5	30.91	39.0	400.1	43,430	28 9	34.4	1,339,000	446,800	.40	3,160,000	3,132,000	86.9
Nov. 9	28.58	20.8	324.3	41,860	26.7	31.7	1,194,000	361,000	.43	3,334,000	3,308,000	83.7
Nov. 9	28.88	20.8	326.8	39,990	29.1	34.1	1,152,800	359,400	.41	3,207,000	3,183,000	80.0
Nov. 11	28.86	20 3	323.2	39,620	27.1	32.2	1,141,000	356,500	.41	3,201,000	3,178,000	79.3
Nov. 11	28.52	20.2	326.8	39,270	30.2	34.9	1,118,000	358,800	.40	3,115,000	3,093,000	78.6
Nov. 12	27.42	19.9	323.6	37,280	30.2	35.4	1,020,000	355,000	.37	2,873,000	2,850,000	74.6
Nov. 16	26.78	20.14	326.5	38,580	25.2	30.2	1,031,000	364,200	.36	2,854,000	2,831,000	77.2
Nov. 16	28.46	20.16	321.2	37,840	27.81	33.15	1,074,000	356,900	.39	3,038,000	3,010,000	75.7
Nov. 17	28.73	20.5	328.7	38,870	28.9	33.9	1,114,000	364,400	.39	3,080,000	3,056,000	77.8
Nov. 18	29.43	20.17	32.05	39,680	28.9	32.8	1,165,000	355,300	.42	3,299,000	3,279,000	79.4
Nov. 18	28.61	20.1	326.0	38,560	28.6	33.7	1,100,000	361,400	.39	3,068,000	3,044,000	77.2
Nov. 19	29.09	20.8	329.1	39,930	29.4	34.5	115,900	364,500	.41	3,204,000	3,180,000	79 9
Nov. 20	28.97	25.63	323.2	39,280	31.94	36.9	1,130,000	357,500	.41	3,203,000	3,178,000	78.6
Nov. 20	28.02	20.1	325.2	38,630	36.0	41.2	1,080,000	353,500	.39	3,055,000	3,030,000	77.3
Nov. 23	38.69	26.14	331.1	34,610	27.9	33.5	1,330,000	368,700	.47	3,656,000	3,623,000	69.2
Nov. 24	36.94	23.2	330.7	32,860	30.0	35.9	1,211,000	366,300	.42	3,334,000	3,306,000	65.7
Nov. 30	36.40	25.4	330 7	35,500	23.9	29.5	1,260,000	367,000	.44	3,434,000	3,402,000	71.0
Dec. 2	36.11	31.19	322.8	32,750	24.65	29.99	1,180,000	358,900	.42	3,288,000	3,261,000	65.5
Dec. 2	37.24	27 9	326.8	32,100	28.1	34	1,193,000	360,300	.43	3,311,000	3,278,000	64.2
Dec. 3	36.71	26.5	320.0	31,890	26.6	32.4	1,168,000	353,900	.42	3,301,000	3,271,000	63.8
Dec. 7	30.01	13.16	200.5	26,480	26.2	30.6	793,100	221,000	.46	3,589,000	3,563,000	53.0
Dec. 7	28.38	12.55	184.9	26,180	24.31	28.42	741,700	204,200	.47	3,631,000	3,603,000	52.4
Dec. 8	25.55	11.4	14.6	21,440	26.8	31.9	546,400	202,600	.35	2,696,000	2,675,000	42.9
Dec. 9	25.09	10.4	184.3	21,090	27.0	32.2	526,400	202,200	.33	2,603,000	2,583,000	42.2
Dec. 9	24.96	10.8	188.3	20,880	28.3	33.7	519,800	206,100	.32	2,523,000	2,501,000	41.8
Dec. 10	25.08	20.6	186.6	21,130	26.9	31.6	528,700	206,000	.33	2,566,000	2,548,000	42.3
Dec. 11	24.29	10.7	178.2	21,510	27.2	31.8	521,400	195,700	.34	2,664,000	2,645,000	43.0
Dec. 11	24.65	11.0	186.8	22,520	27.8	32.5	553,800	204,900	.35	2,702,000	2,683,000	45.1

TESTS ON DAVIS PUMP.

Date.	Revolutions per minute of pump shaft.	Suction head in feet.	Discharge head in feet.	Velocity head in feet.	Total head in feet.	Power given to pump. (H. P.)	Work done by pump. (H. P.)	Efficiency. (Per cent.)	Capacity. (Apparent.)	Capacity. (Real.)
1896.										
Oct. 5	20.5	7 0	35.8	0.1	43.9	1.06	.54	50.7	65.4	48.6
Oct. 5	20.5	6.9	43.6	0.1	51.6	1.06	.55	51.9	65.4	42.3
Oct. 6	20 4	6.8	48.5	0.1	53.4	1.10	.60	54.5	65.0	42.3
Oct. 7	14.1	6.6	49.9	0.0	57.5	.68	.39	56.9	44.8	26.6
Oct. 7	20.4	6.5	39.7	0.0	47.2	.97	.50	51.5	65.0	41.8
Oct. 12	20.5	6.3	70.4	0.1	77.8	1.24	.86	69.2	65.3	43.6
Oct. 14	20.5	6.6	59.1	0.1	66.8	1.58	.97	61.2	64.9	57.5
Oct. 14	20.3	7.4	20.1	0.1	28.6	.71	.45	63.7	64.7	62.4
Oct. 15	20.3	6 3	82.2	0.2	89.7	1.99	1.39	70.0	64.7	61.5
Oct. 19	20.5	6.6	62.1	0.1	69.8	1.51	1.11	73.8	65.2	63.0
Oct. 19	20.3	6.2	68.8	0.2	76.2	1.58	1.19	75.4	64.6	61.8
Oct. 21	20.4	6.7	40.2	0.1	48.0	.88	.76	86.3	65.0	63.1
Oct. 28	20.2	6 2	64.4	0.2	71.8	1.26	1.12	88.9	64.4	61.9
Oct. 29	20.5	5.6	57.3	0.1	64.0	1.11	1.02	91.9	65.4	63.6
Nov. 2	20.5	5.8	57.7	0 1	58.6	1.11	.94	84.9	65.4	63.6
Nov. 2	20.5	5.9	50.4	0.1	57.4	1.09	.93	84.7	65.3	64.0
Nov. 3	20.5	6.1	57.5	0.1	64.7	1.11	1.03	92.7	65.4	63.1
Nov. 4	20.5	6.1	51.0	0.1	58.2	1.05	.91	86.5	65.2	61.5
Nov. 4	20.3	5.6	56.6	0.1	63.3	1.27	.99	77 7	64.6	61.8
Nov. 5	25.2	6.0	50.6	0.2	57.8	1.46	1.13	77.6	80.1	77.6
Nov. 9	25.8	5.6	98.8	0.2	105.6	2.74	2.11	76.9	82.0	79.0
Nov. 9	24.8	5.7	92.2	0.2	99.1	2.47	1.90	77.2	79.1	76.1
Nov. 11	25.0	6.5	87.5	0.2	95.2	2.37	1.81	76.7	79.6	75.5
Nov. 11	24 8	6.5	92.4	0.2	100.1	2.47	1.89	76.3	78.9	74.8
Nov. 12	25.0	6.7	78.1	0.2	86.0	2.04	1.64	80.6	79.7	75.7
Nov. 18	25.2	5.8	79.0	0.2	86.0	2.09	1.68	80.2	80.2	77.3
Nov. 18	25.0	5.8	70.9	0.2	77 9	2.01	1.44	71.7	79.5	73.9
Nov. 19	25.2	6.6	74.4	0.2	82.2	1.97	1.59	80.6	80.2	76.6
Nov. 23	24.9	7.4	88.5	0.2	97.1	2.26	1.86	82.4	79.3	76.0
Nov. 24	25.0	6.8	64.0	0.2	72.0	1.79	1.40	78.0	79.7	76.8
Nov. 30	16.0	7.7	155.4	0.1	164.2	2.59	1.94	74.8	50.8	46.7
Nov. 30	15.5	7.6	117.0	0.1	125.7	1.97	1.49	75.7	49.5	47.1
Dec. 1	18.4	7.6	161.6	0.1	170.3	3.21	2.38	74.0	58.5	55.3
Dec. 2	20.5	7.6	127 1	0.1	135.8	2.59	2 11	81.4	65.4	61.6
Dec. 3	18.9	7.2	165.8	0.1	174.1	3.18	2.48	78.0	60.1	56.5
Dec. 4	20.5	7 5	155.0	0.1	163.6	3.16	2.55	80.8	64.7	61.8
Dec. 4	17.3	7.3	150.5	0.1	158.9	2.67	2.05	77.0	55.0	51.2
Dec. 7	21.1	7.0	150.5	0.1	158.6	3.27	2.48	76.0	67.3	62 0
Dec. 7	21.1	7.1	144.5	0.1	152.7	3.15	2.50	79.4	67.5	64.9
Dec. 8	22.3	7.3	152.4	0.2	161.0	3.40	2.68	78.8	71.0	66.0
Dec. 9	22.1	6.5	152.2	0.2	159.9	3.43	2.55	74.4	70.2	63.2
Dec. 9	25.0	6 9	101.6	0.2	109.7	2.66	2.08	78.1	79.6	75.0
Dec. 10	24.6	6.8	64.9	0.2	72.9	1.76	1.38	78.6	78.1	75.6
Dec. 11	25.3	6.8	95.2	0.2	103.2	2.31	2.03	88.2	80.6	78.1
Dec. 11	26.6	7.0	107.4	0.3	115.7	2.73	2.38	87.2	84 6	81 6

There was a distance of one foot between the points where the suction head and the discharge heads were measured. This is included in the values of total head.

TESTS ON ROTARY PUMP.

Date.	Revolutions of pump per minute.	Pressure of discharge. (Pounds per sq. in.)	Total head. (Feet.)	Capacity. (Gallons per minute.)	H. P. of engine. (Pumping.)	H. P. of engine. (Not pumping.)	H. P. delivered to pump.	H. P. delivered by pump.	Efficiency of pump.	Friction of pump.
1897.										
Mar. 2	235	30.4	85.8	836	68.9	31	37.9	18.2	48.2	51.8
Mar. 4	237	31.1	91.3	843	70.8	31.1	39.7	19.5	49	51
Mar. 9	236.9	30.4	88.8	831	70.9	35.1	35.8	18.6	52	48
Mar. 9	235.5	30.6	90.3	823	74.3	36.2	38.1	18.8	49.2	50.8
Mar. 15	236	31.2	90.7	833	75.5	35.9	39.6	19.1	48.1	51.9
Mar. 16	236	31.2	92.3	828	73.3	33.7	39.6	19.3	48.7	51.3
Mar. 18	235.7	30.9	90.4	823	69.4	33.4	36	18.8	52.1	47.9
Mar. 18	236	29.7	85.5	807	66.5	32.3	34.2	17.4	50.9	49.1
Mar. 19	236	28.4	82.9	788	66.6	33.3	33.3	16.5	49.5	50.5
Mar. 19	235.9	29.9	87.5	818	68.1	33.1	35	18.1	51.6	48.4
Mar. 22	201.7	30.36	89.6	818	67.7	31	36.7	18.5	50.4	49.6
Mar. 23	235.6	30.5	90.9	820	70.8	32.7	38.1	18.8	49.4	50.6
Mar. 23	222.4	30.02	88.3	818	69.3	34.6	34.7	18.2	52.5	47.5
Mar. 25	233	30.53	90.6	818	71.1	34	37.1	18.7	50.4	49 6
Mar. 29	236	30	88.3	818	66.6	30.3	36.3	18.2	50.2	49.8
Apr. 1	237.2	30.41	88.3	820	69.2	31.5	37.7	18.3	48.5	51.5
Apr. 1	236.5	30.32	89.4	820	68.4	30.5	37.9	18.5	48.8	51.2
Apr. 2	237.2	30.5	89.3	825	68.5	31.2	37.3	18.6	49.9	50.1
Apr. 5	236.8	30.6	90.2	820	70.9	33.5	37.4	18.7	50	50
Apr. 5	243.6	29.5	86.5	807	66.2	30	36.2	17.6	48.6	51.4
Apr. 6	238.1	30.7	90.1	825	66	30	36	18.8	52.1	47.9
Apr. 8	238	30.9	89.7	825	61.5	23.4	38.1	18.7	49	51
Apr. 9	237.2	29.8	88.5	813	67.1	30.5	36.6	18.1	49 6	50.4
Apr. 12	237.8	29.81	90.6	807	59.7	23.3	36.4	18.4	50.7	49.3
Apr. 13	238.6	30.5	89.9	828	59.5	23.8	35.7	18.8	52.6	47.4

THE CONCENTRATION OF ORES.

By ROBERT H. RICHARDS.

Read January 13, 1898.

QUARTZ ores, which are mined from veins in the solid rock, contain valuable minerals which are usually of high specific gravity; for example, galena carrying lead, or copper pyrites carrying copper, associated with light-weight minerals; for example, quartz, calcite, etc., which are of little or no value.

Since the smelting process is expensive, ores that are smelted at once without concentration may cost more than the metal contained in them is worth, leaving a balance of indebtedness as the result of the transaction. For example, suppose lead smelting costs $10.00 per ton, and the lead ore contains 8 per cent. of lead, 10 per cent. of which is lost in smelting, then the account for treating 100 tons would stand as follows:

Cr.	100 tons ore at $10.00 smelting charges	$1,000.00
Dr.	100 tons ore at 8% lead, 10% lost in smelting, yields 14,400 pounds lead at 3 cents	432.00
	Balance of loss	$568.00

To overcome this difficulty and to substitute profit for loss, the processes of concentration of ores have been developed. By them, the values contained in 2 tons, 10 tons, or even 20 tons may be concentrated into 1 ton, which is proportionally enriched.

The large quantity of mine ore can afford to pay the low price of concentration, while the small quantity of much enriched concentrates is in the best condition to pay the high smelting charges and to leave a good margin for profit.

For example, suppose, in addition to the figures above, that con-

centration costs 60 cents, and that 15 per cent. is lost in concentrating, then we have:

Cr.	100 tons ore at $0.60 concentrating expense	$60.00
	13 tons 1,200 pounds concentrates at $10.00 per ton smelting charges	136.00
		$196.00
Dr.	13 tons 1,200 pounds concentrates at 50% lead, and 10% loss in smelting, yields 12,240 pounds lead at 3 cents per pound,	$367.20
	Balance of profit	$171.20

The methods of concentration depend upon certain properties of minerals, of which the following are the most important: *Structure and cleavage* influence the shapes of the particles resulting from crushing, some breaking into rounded or cubical forms, and others into flat shapes. These different shapes have an important bearing on the power of the grains to settle in water. *Mineral aggregation.* — When the minerals occur in large crystals, it is comparatively easy to sever the valuable from the waste by breaking, and then to separate them; but if the valuable minerals are finely disseminated in the waste rock the separation becomes more difficult. *Hardness, tenacity, and brittleness.* — The harder the minerals the greater the wear on the crushing machinery. Certain minerals, such as talc, gypsum, and native copper, though soft are very tough, and are, therefore, not easily broken. Other minerals, such as certain varieties of quartz, though hard are very brittle. These tend to form a large amount of slimes from which it is difficult to extract the values, because they do not readily settle either in water or in air. *Specific gravity.* — Differences in specific gravity furnish the most valuable means of separating minerals. Nearly all of the concentrating machines are based primarily upon this principle. *Adhesion.* — A clean particle of gold that has become coated with mercury will adhere to an amalgamated copper plate, and is thus separated from the quartz with which it was associated. *Magnetism* is utilized for the enrichment of some kinds of iron ore, and also for certain other special cases. *Porosity.* — Certain minerals, such as pyrites, become porous by roasting. Their specific gravities are thus decreased, and they can then be separated from minerals from which they could not be separated before. *Greasiness.* — When minerals are finely divided they are apt to act as though they were greasy, and float on the sur-

face of water. This is frequently a cause of loss, especially in the treatment of cassiterite, of native copper, and of native gold. *Decrepitation.* — Certain minerals, such as calcite, barite, and fluorite, when heated fly to pieces, while other minerals are not so affected. This treatment, applied to a carefully sized product, may permit a separation by subsequent screening.

There are two chief steps in concentration: the breaking up of the rock to sever the valuable minerals from the quartz, and the subsequent separation of these "values" from the worthless portions.

For coarse breaking the Blake, Dodge, and Gates crushers are used. Each machine has special qualities which adapt it to its work, but they all act by approaching and receding crusher plates, between which the ore is broken.

For fine crushing a great variety of machines are employed, among which may be mentioned steam stamps and gravity stamps, which break the ore by a blow; and rolls, Huntington roller mill, and Bryan roller mill, which break the ore by rolling pressure. All of these machines find appropriate places in one or another of the mills, according to their fitness for the work to be done, and the preference of the manager. For example, the gravity stamp is almost universally used for crushing gold ores, the steam stamp is the only machine now in use for crushing the native copper of the Lake Superior region, rolls are almost universally employed for lead ores and sulphide copper ores, and the Huntington and Bryan mills are much used for the finest crushing of the various ores.

The concentration proper, or the separation of the "values" from the refuse in the crushed material, is divided into two kinds of work, namely: the preliminary work, which separates the materials into groups or classes, which may or may not be enriched thereby, and final work, which separates the "values" from the refuse of each class, the former going to the smelter, the latter to the dump.

The preliminary separators include the grizzly or bar screen, the drum screens (trommels), the hydraulic classifiers, and the Spitzkasten. The screens separate the materials which come to them into coarse and fine, and a series of screens, with sizes ranging from very large spaces in the first screen down to very small in the last, will give a series of products ranging from the largest down through all the sizes to the finest. Each of these sizes is kept separate from all the others and sent to its proper place in the treatment.

The hydraulic classifier subjects the sands which pass through the finest screen to an upward current of water in a confined space, and the particles which have sufficient weight to settle down through the current can go out through a discharge spigot below, while those which cannot do so, go over and try their luck in the next pocket of the classifier, where an upward stream of less force awaits them, and so on to a third and a fourth pocket. The overflow passes on to the "Spitzkasten," which has three or more pointed boxes, each larger than the last. In this the particles settle from the carrying current of water which passes over the surface to the discharge end of the box, and no upward current is used. The second is wider than the first and so drops finer particles; thus here, too, a series of graded sizes is made. Looking in review over the products of the preliminary separators, it will be seen that the ore has been divided up into a series of sizes ranging from the coarsest, obtained from the first screen, down to the finest size of the Spitzkasten. The products from the classifier and the Spitzkasten, however, are both what are called "water sorted products," which differ from the "sized products" obtained by the screens, in that the quartz and galena in any one of the latter are of the same size, while the quartz particles are much larger than the galena in the former products.

Having examined into the preliminary machines, we will next take up the final concentrators which deliver the dressed ore ready for shipment to the smelter. These include picking tables, jigs, vanners, shaking tables, and slime tables. They all turn out finished concentrates for the smelter. The waste from the coarser machines, however, may require recrushing to recover certain included or attached particles of the valuable minerals called middlings, which failed to be severed from the quartz in the first crushing. These recrushed middlings are then washed again. Waste from the finer sizes is refuse.

On picking tables, rich minerals above 1 inch in size may be picked out by hand for the smelter; the rest goes back to crushers.

The jigs take the sizes next below that treated by the picking table, each of the sizes having its own jig down to nearly the last of the classifier products. The jig treats the ore on a sieve by the action of an up and down movement of water. When screen-sized quartz and galena are subjected on an immersed sieve to an upward current of water which loosens up the ore, the galena being the heavier drops below the quartz and a separation is effected. As the ore is fed con-

tinuously to the jig, the light quartz passes off by the overflow, while means are provided for drawing off from the sieve the accumulation of galena as fast as it forms.

When a water-sorted product from the classifier is fed to the jig, the downward movement which follows each lift is quite as important as the upward movement, for the downward current draws down the small particles of galena through the interstices between the large grains of quartz. The galena passes down through the sieve in this case, and the quartz passes off at the overflow as before.

Vanners are used to make the final separation of the last products of the classifier or the first of the Spitzkasten, or both. The Frue vanner is an endless belt 4 feet wide, with flanges or ribs on the edges to keep the pulp from running off the sides. The belt runs upon end rollers 12 feet apart, with little supporting rollers all along. It has a gentle slope; the belt moves slowly up hill, and it is given rapid vibrations sidewise. When water and ore are distributed across this belt they are subjected to three actions: at first the vibrations settle the rich minerals upon the belt with the quartz floating above it; secondly, the slow upward travel of the belt draws the former towards the upper end of the machine, where they are discharged; thirdly, the downward flow of the water carries the quartz with it to be discharged at the lower end of the machine, and thus separation is effected. The fact that the quartz is larger and galena smaller in size is of less consequence for this machine than for the slime tables.

The slime tables, which treat the two or three last products of the Spitzkasten, including the finest mud, are generally circular tables of about 17 feet diameter, with a very slight inclination from the center toward the circumference; they revolve continuously and very slowly in one direction, so that if the fine slimes from the Spitzkasten are fed on one side, at the center, and clean water on the other side, the water will in both cases flow down and over the margin of the table, carrying with it the grains that are most affected by the current. The large grains of quartz are more affected than the small grains of galena, for two reasons: first, they project up higher into the water film where the water is moving faster; and secondly, the quartz is of less specific gravity, and, when other things are equal, it will be moved more rapidly than galena. These conditions, then, serve admirably, first, by the aid of the water which brings the ore, and secondly, by the clean wash water on the other side of the table, to push

the quartz off the margin of the table and to retain the galena until it reaches the wash-off jet, which forcibly removes it, preparing the table to treat the next coming ore.

A number of shaking tables have been designed which may take the place of vanners or slime tables, or of both. They all have a bump or a jerk given to the tables, which acts either at right angles to the flow of the water film or diametrically opposite to it, and in every case the heavy minerals are settled below the quartz by the jerk, and are thrown farther in the direction of the jerk than the quartz. The quartz, on the other hand, as it is floating in the upper layer, is more affected by the water current than are the heavy minerals. By adjusting the slope of the table and the quantity of water these two opposing forces are made to deliver the valuable minerals at one point and the quartz at another.

A great deal of study by mill men and engineers has been put upon the question as to how the machines shall be arranged in a mill to turn the good qualities of each machine to the best account, and much difference of opinion still exists in regard to it. The more we study the principles of action of these machines, the better are we qualified to discuss the matter intelligently and to contribute suggestions of real value towards the solution of the question.

The principles which govern the action of some of the machines have been stated in the descriptions which have just been given. Some results of investigations into the laws which regulate those principles will now be given. For example: In jigging, the first question which arises is, "Does suction help or hinder the jigging of screen-sized products; also of water-sorted products?" Tests were made to decide these questions by varying the amount of suction used, and also by varying the size of the valuable minerals while the quartz remained the same. The results are shown in the table, and the ease or difficulty of jigging is shown by the number of pulsions needed to separate the per cent. indicated.

The figures marked with (*b*) clearly show that screen-sized products should be jigged with as little suction as possible, for, with much suction 2,129 pulsions were needed, against 147 pulsions with no suction. On the other hand, figures (*a*) show that to jig water-sorted products much suction greatly helps the process, for, with much suction, only 297 pulsions were needed to effect an almost perfect separation, while with no suction separation was impossible, the finer sizes of valuable minerals floating on top of the quartz.

This table shows further that when the valuable mineral is so heavy that the diameter of the quartz is 3.52 $\left(= \frac{.0683}{.0195}\right)$ or more times that of the former, suction acts with great ease and rapidity; but when the figure is much less than 3.52 it is difficult jigging, unless the jig has a very coarse sieve upon it.

Diameter of quartz	.0683 ins.	.0683 ins.	.0683 ins.
Diameter of valuable minerals	.0683 ins.	.0262 ins.	.0195 ins.
WITH STRONG SUCTION.			
Pulsions needed	2,129 *b*	.1759	297 *a*
Per cent. separated	96	95	95
WITH MILD SUCTION.			
Pulsions needed	306 *b*	846	1,382 *a*
Per cent. separated	99	100	98
WITH NO SUCTION.			
Pulsions needed	147 *b*	496	0 *a*
Per cent. separated	98	50	0

The ultimate effect also of pulsion, or the upward current of a jig, has been studied in a vertical tube, in which mixed sizes of quartz and galena from $\frac{1}{10}$ inch in diameter down to dust, were subjected to an upward current of water, which was tried both as a pulsating intermittent current, and also as a steady current, with identically the same results. It was found that after all the heaviest of the galena had settled beneath the quartz, and equilibrium of the particles in the quicksand had been attained, alongside the quartz small grains of galena were balanced in equilibrium, and when these were taken out and measured, the diameter of the quartz was found to be about 5.8 times that of the galena. This test was tried and figures obtained for a number of minerals of different specific gravities, among which are the following: The specific gravity of the quartz being 2.640 —

	Specific gravity.
Quartz is 8.6 times the diameter of copper	8.479
Quartz is 5.8 times the diameter of galena	7.586
Quartz is 3 7 times the diameter of arsenopyrite	5.627
Quartz is 2.8 times the diameter of pyrrhotite	4.508
Quartz is 2 1 times the diameter of sphalerite (blende)	4.046

These are called the "hindered settling" ratios, because the particles are bumping against and hindering one another.

This table, taken in connection with the previous one, shows that classifier products of quartz and pyrrhotite, and still more so of quartz and blende, will be difficult to work by suction unless a very coarse sieve is used on the jig.

The next question which occurs affects both the jigging and the slime table work. It is, "What is the ratio of quartz to valuable mineral in the products of the hydraulic classifier and the Spitzkasten?" Measurements have been made of the diameter of particles of galena and quartz, when settling freely and with the same velocity. The following table gives some of the results of these measurements:

DIAMETERS OF THE QUARTZ AND GALENA PARTICLES WHICH ARE EQUAL-SETTLING IN THE UPWARD CURRENTS SPECIFIED WHEN TREATED UNDER FREE-SETTLING CONDITIONS, TOGETHER WITH THE OBSERVED AND CALCULATED DIAMETER-RATIOS.

Particles fall in current of inches per second.	Particles rise in current of inches per second.	Diameter of particles in inches.		Ratio between diameters of particles actually obtained.	Diameter of particles in millimeters.		Particles fall in currents of millimeters per second.	Particles rise in currents of millimeters per second.	Ratio between diameters of particles averaged by a curve.
		Quartz.	Galena.		Quartz.	Galena.			
.000	.050	.00119*	.00076*	1.55	.0301*	.0194*	0.00	1.26	1.54
.050	.099	.00132	.00078	1.69	.0335	.0198	1.26	2.51	1.68
.099	.199	.00224	.00115	1.95	.0568	.0292	2.51	5.05	1.82
.394	.577	.00561	.00242	2.32	.1423	.0613	10.01	14.68	2.23
.780	1.186	.0089	.0041	2.18	.2254	.1032	19.80	30.12	2.48
1.186	1.589	.0135	.0051	2.62	.3416	.1305	30.12	40.37	2.61
1.589	1.972	.0153	.0055	2.76	.3880	.1404	40.37	50.08	2.72
2.366	2.769	.0232	.0079	2.95	.5892	.1997	60.09	70.34	2.92
3.552	3.919	.0403	.0135	2.99	1.0234	.3428	90.21	99.54	3.21
5.526	5.918	.0632	.0180	3.52	1.6032	.4560	140.37	150.31	3.54
7.106	7.826	.0778	.0228	3.42	1.9744	.5776	180.51	198.78	3.70

EXAMPLE. — Mixed particles of galena and quartz treated in free space with rising currents of water. Those that fall in 30.12 and rise in 40.37 millimeters per second current, will have diameters .3416 mm. for quartz, .1305 mm. for galena approximately, and the diameter of the quartz will be 2.6 times that of the galena.

* These averages have less value than the others, for the diameters in these cases range from the figures given down to zero.

A hydraulic classifier probably gives products with nearly these ratios. The grains may hinder one another to some extent, and if they do the ratios will be larger, but not so large as the hindered settling ratios. These ratios have also been obtained for a number of minerals, among which are the following:

FREE-SETTLING FACTORS, OR MULTIPLIERS, FOR OBTAINING THE DIAMETERS OF QUARTZ WHICH WILL BE EQUAL-SETTLING WITH THE MINERAL SPECIFIED WHEN SETTLING FREELY IN AMPLE WATER.

	VELOCITY IN INCHES PER SECOND.								
	1	2	3	4	5	6	7	8	9
	MULTIPLIERS.								
Sphalerite	....	1.46	1.05	1.17	1.62	1.64	1.68	1.66	1.56
Pyrrhotite	....	1.73	1.29	1.48	2.00	2.22	2.26	2.13	2.08
Arsenopyrite . . .	....	1.90	1.57	1.89	2.42	2.56	2.72	2.84	2.94
Galena	....	2.71	1.83	2.26	3.00	3.42	3.65	3.76	3.75
Copper	....	2.71	2.00	2.36	3.00	3.20	3.58	3.76	3.75

EXAMPLE. — If a compact particle of galena, falling freely in water, settles 7 inches per second, the particle of quartz of the same shape that will settle at the same rate will be approximately 3.65 times the diameter of the galena.

In regard to the Spitzkasten, the evidence thus far obtained indicates that while the above ratios ("free-settling" ratios) are probably true for the coarser grains of each product, the earlier products will always be contaminated with grains that belong in the latter, a fault which causes loss of rich mineral upon the tables.

The last question which will be discussed in this paper affects the slime tables: "At what angle of slope should a slime table be built, and with what water quantity should it be fed?" To gain facts which will throw light upon these questions, measurements have been made of the lowest angles at which all the grains of quartz in any given free-settling product will roll, the water quantity varying from 1 pound up to 25 pounds per minute on every 2 feet of width of table. A similar set of angles have been measured for the galena, and they are found to be much larger than those of the quartz; in fact, at the angle

where all the quartz rolls, scarcely any of the galena moves. These measurements have all been repeated for a number of different free settled products, giving a range from the finer to the coarser sizes.

The following two tables give these facts for galena and quartz:

GALENA. — ANGLES AT WHICH ALL THE GRAINS MOVE.

Pounds of water per minute on 2 ft. of width.	Millimeters per second of Current which Lifts the Particles.						
	1.26	2.51	5.05	14.68	40.27	50.08	70.34
	Millimeters per second of Current in which the Particles Fall.						
	0	1.26	2.51	10.01	30.12	40.37	60.09
	Galena Finish-Angles (Minimum of Three Trials in Most Cases).						
1	15°20′	.....	9°00′	12°45′	10°40′	....	....
2	12°20′	.....	11°00′	9°30′	10°00′	....	....
4	7°50′	10°50′	6°15′	7°10′	5°30′	7°30′	9°00′
6	3°05′	6°00′	4°15′	5°15′	4°40′	5°55′	7°30′
8	.....	4.30′	5°00′	4°45′	3°55′	4°55′	6°10′
10	0°50′	.....	.....	4°15′	4°00′	4°20′	5°05′
12	.....	.....	.....	4°00′	3°50′	4°05′	4°15′
14	1°05′	.....	.....	4°15′	4°10′	4°20′	4°50′
16	.....	.....	.....	4°20′	4°05′	4°10′	4°25′
18	0°50′	.....	.....	4°30′	4°40′	4°35′	4°15′
20	.....	.....	.....	4°30′	4°55′	5°05′	4°15′
22	.....	.....	.....	5°05′	5°05′	5°00′	4°50′
25	.....	.....	.....	5°35′	7°20′	5°30′	4°55′

QUARTZ. — ANGLES AT WHICH ALL THE GRAINS MOVE.

Pounds of water per minute on 2 ft. of width.	Millimeters per second of Current which Lifts the Particles. 1.26	2.51	5.05	14.68	40.37	50.08	70.34
	Millimeters per second of Current in which the Particles Fall. 0	1.26	2.51	10.01	30.12	40.37	60.09
	Quartz Finish-Angles (Maximum of Three Trials in Most Cases).						
1	4°	3°20′	1°55′	3°45′	11°05′	7°30′	8°40′
2	3°40′	2°35′	2°25′	3°25′	7°30′	5°20′	5°25′
4	2°40′	2°30′	2°20′	3°00′	3°50′	3°10′	3°15′
6	1°05′	2°35′	2°00′	2°40′	3°10′	3°10′	2°45′
8	.....	2°15′	2°10′	2°40′	2°50′	2°50′	2°35′
10	0°50′	2°15′	2°00′	2°25′	2°50′	2°45′	2°55′
12	.....	1°35′	2°20′	2°05′	3°05′	3°00′	2°40′
14	1°05′	2°05′	2°00′	2°40′	3°30′	2°55′	3°15′
16	.....	1°40′	1°35′	2°00′	3°30′	2°55′	3°10′
18	0°50′	1°20′	1°40′	1°40′	3°15′	2°45′	3°25′
20	.....	2°15′	1°45′	2°30′	3°10′	2°25′	2°45′
22	.....	1°30′	1°20′	1°40′	2°05′	2°45′	4°00′
25	.....	1°30′	1°55′	1°50′	2°10′	2°20′	2°40′

Mill practice of this country generally puts about 10 pounds of water on a slime table for every two feet of periphery. Admitting that this has been settled by practice, we examine the tables and find that 3° of slope will cause all the quartz to roll off, while practically none of the galena goes. These adjustments will work satisfactorily for all sizes except the very finest slimes, and of these the whole of the galena may be lost. To catch this galena, we turn again to the tables and see very favorable figures, if perhaps, 6° or even 7° slope was used and only 2 pounds of water on 2 feet of width; for under these conditions the quartz will all roll at 3°40′, while the galena does not roll until 12°20′ is reached.

INVESTIGATION OF THE THEORY OF THE SOLUBILITY EFFECT IN THE CASE OF TRI-IONIC SALTS.

By ARTHUR A. NOYES and E. HAROLD WOODWORTH.

Received January 20, 1898.

The theory of the effect of salts on the solubility of one another has been quite thoroughly tested and confirmed in the case of di-ionic salts having one ion in common.[1] The solubility of tri-ionic salts in the presence of other salts has, however, been much less investigated. To be sure, the theory of the phenomenon has been developed already, and has been partially tested by experiments with lead chloride in the presence of other salts.[2] There was found, however, to be only an approximate agreement between the theory and the facts, probably because the dissociation-values involved are uncertain. Moreover, the theory could not be tested in the case where a salt with a common bivalent ion was added, probably owing to the fact that a double salt was formed. Further investigation of the subject seems, therefore, to be desirable.

To this end we have determined the solubility of lead iodide in pure water, and in solutions of potassium iodide and of lead nitrate of varying strengths. We made use of lead iodide because of its slight solubility (one molecular weight in about 600 liters); for in such dilute solutions the influence of the two substances on the dissociation of one another is hardly appreciable, and the tendency to the formation of double salts is ordinarily very slight — two phenomena which often have a disturbing influence in concentrated solutions. In order to determine the solubility, we have measured the electrical conductivity of the saturated solutions, and subtracted from it the conductivity of the water or of the solutions before treating with lead iodide. This method has the advantage of greater convenience over the analytical

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[1] Compare especially, Noyes and Abbot: Ztschr. phys. Chem., **16**, 1, 125.

[2] Noyes: Ztschr. phys. Chem., **9**, 626.

determination; and in this case it is especially well adapted, as it furnishes directly a knowledge of the concentration of the ions, so that it is not necessary to consider dissociation-values.

Two samples of each of the three salts were prepared by different methods. These samples were in all cases shown to be exactly alike so far as the conductivity of their solutions was concerned, which indicates that the substances were in all probability pure. One sample of the potassium iodide was prepared by treating the commercial chemically pure salt with alcohol until it was about one-half dissolved, and by subsequent crystallization from this solution by evaporation. The other sample was obtained by crystallizing from water the residue left undissolved by the alcohol. The lead nitrate was obtained in one case by crystallization of a commercial sample from water; in the other, by precipitation with nitric acid followed by crystallization from water. One sample of lead iodide was prepared by metathesis from lead acetate and potassium iodide; the other, by dissolving a commercial preparation in a strong potassium iodide solution, and then diluting with water. In both cases the salt was purified by crystallizing twice from water.

The determinations of solubility were carried out as follows: Small 40 c.c. glass-stoppered bottles were charged with an excess of the solid lead iodide and with pure water or with solutions of lead nitrate or potassium iodide; the stoppers were coated with paraffin, and the bottles were rotated for five hours in a thermostat by means of an apparatus previously described.[1] The solutions were then allowed to settle for a short time, and blown out by means of a wash bottle arrangement into a resistance cell of the Arrhenius type; and the conductivity was measured in the usual way.[2] All the determinations of solubility and measurements of conductivity were carried out at 25° C. In all cases duplicate determinations of the solubility were carried out in such a way that the condition of saturation was approached from both sides — that of supersaturation and that of undersaturation. Moreover, in order to make certain of the purity of the lead iodide, not only were the two different samples used, but each sample was treated also with successive amounts of water, and the conductivity of the corresponding solutions determined. A complete agreement was found to exist.

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[1] Ztschr. phys. Chem., **9**, 606.

[2] Ostwald: Ztschr. phys. Chem., **2**, 561.

The following tables contain the specific conductivities (multiplied by 10^{-7}) expressed in Siemen's units. In all cases the conductivity of the water used (which was equal to 9×10^{-7}) has been subtracted.

CONDUCTIVITY OF WATER SATURATED WITH LEAD IODIDE.

	I.	II.	III.	IV.	Mean.
Undersaturated	4016	4016	4023	4030	4021
Supersaturated	4039	4041	4042	4041	4041

CONDUCTIVITY OF SOLUTIONS OF POTASSIUM IODIDE SATURATED WITH LEAD IODIDE.

Concentration of the Potassium Iodide.	0.003077 Equivalents per Liter.		0.002000 Equivalents per Liter.	
Condition of the Solution.	Undersaturated.	Supersaturated.	Undersaturated.	Supersaturated.
I	6174	6184	5316	5343
II	6172	6200	5310	5335
Mean	6173	6192	5313	5339

CONDUCTIVITY OF SOLUTIONS OF LEAD NITRATE SATURATED WITH LEAD IODIDE.

Concentration of the Lead Nitrate.	0.003077 Equivalents per Liter.		0.002000 Equivalents per Liter.	
Condition of the Solution.	Undersaturated.	Supersaturated.	Undersaturated.	Supersaturated.
I	6807	6783	5798	5800
II	6791	6799	5796	5784
III	6799	6802	....	....
Mean	6799	6795	5797	5792

A consideration of the results in these tables shows that the comparable values agree closely with one another, although the determinations were carried out with different salts and at different times. The supersaturated solutions are, to be sure, about half of one per cent. higher than the undersaturated, except in those experiments where lead nitrate was used, in which case they were practically equal. In the calculation of the corresponding concentrations of the

ions described below, the mean of the supersaturated and of the undersaturated values was used always.

The specific conductivities of the pure potassium iodide and lead nitrate solutions are given in the following tables. In the upper half are given the conductivities of the freshly-made solutions, and in the lower half, those of the same solutions after they had been rotated for the same time and under the same conditions as prevailed in the solubility experiments.

CONDUCTIVITY OF THE SOLUTIONS OF POTASSIUM IODIDE AND LEAD NITRATE BEFORE TREATMENT WITH LEAD IODIDE.

	Potassium Iodide Solution.		Lead Nitrate Solution.	
Equivalents per liter . . .	0.003077	0.002000	0.003077	0.002000
First solution	4247	2809	3782	2498
Second solution	4257	2807	3785	2497
Mean	4252	2808	3784	2498
First solution	4288	2836	3771	2487
Second solution	4288	2849	3774	2487
Mean	4288	2843	3773	2487

In order to ascertain the conductivity of the dissolved lead iodide in the presence of the two other salts, we have subtracted the mean values in the lower half of this table from those of the saturated solutions in the two previous tables; it being assumed that the conductivity at these dilutions is an additive property. That this assumption is approximately correct may be concluded from the fact that the lead nitrate and the potassium iodide at a dilution of 500 liters are dissociated 93.6 and 98.5 per cent. respectively, while at a dilution of 325 liters they are 92.0 and 96.9 per cent. dissociated respectively; in other words, the degree of dissociation is so great, and changes so little with increasing concentration, that it cannot be appreciably affected by the presence of the relatively small amount of lead iodide ions. In order, now, to derive from the conductivity-values the corresponding concentrations of the ions, it is only necessary to divide them by the molecular conductivities of the respective

salts at infinite dilution. We take as the values of the rates of migration those calculated by Bredig, namely, $K = 70.6$, $I = 72.0$, and $NO_3 = 65.1$. The value for the lead ion has, so far as we know, not as yet been derived. Franke[1] has measured the conductivity of lead nitrate in dilute solution, from which the rate of migration can be calculated. Since, however, this value is for our purpose of fundamental importance, we thought it advisable to confirm the accuracy of his determinations by measurements of our own. We have, therefore, determined the conductivity of both of our samples of lead nitrate at different dilutions. Our values (represented by μ_1 and μ_2, the mean value by μ), together with those of Franke (μ_{Fr}), are given in the following tables:

EQUIVALENT CONDUCTIVITY OF LEAD NITRATE.

v	μ_1	μ_2	μ	μ_{Fr}
256	120.8	120.9	120.9	122.2
325	122.6	122.8	122.7	....
500	124.9	124.8	124.9	....
512	125.2	125.3	125.3	125.9
1024	128.2	127.7	128.0	127.1

As is seen, the conductivities of our two samples agree almost completely with each other, and also fairly well with those of Franke. To obtain the value at infinite dilution we make use of Bredigs'[2] extrapolation values, which have been derived from a consideration of a large number of salts. The values extrapolated in this manner from our measurements are 132.9, 133.3, and 134.0 for the three dilutions, 256, 512, and 1024 liters respectively. We, therefore, take the mean, 133.4, as the value of the conductivity of the lead nitrate at infinite dilution.

Since the rate of migration of the NO_3-ions is equal to 65.1, that of the lead ion must be 68.3, from which it follows that lead iodide has for its value at infinite dilution 140.3. Finally, the value derived for potassium iodide at infinite dilution from the above given rates of migration is 142.6. Now if the corresponding specific conductivities

[1] Ztschr. phys. Chem., **16**, 471.

[2] Ztschr. phys. Chem., **13**, 198.

are divided by these limiting values, we obtain the concentrations of the ions which correspond to the measurements of conductivity given above. The results of these divisions are presented in the following table, those in the case of the lead iodide being placed under the heading "found."

CONCENTRATION OF THE IONS IN THE SATURATED SOLUTIONS.

Potassium iodide ions.	Lead Iodide Ions.		Lead nitrate ions.	Lead Iodide Ions.	
	Found.	Calculated.		Found.	Calculated.
0.00	0.002873	.....	0	0.002873	.....
0.001969	0.001770	0.001731	0.001872	0.002358	0.002366
0.002982	0.001351	0.001296	0.002837	0.002155	0.002175

It is readily seen from these numbers that the solubility in the solutions of potassium iodide, as well as in those of the lead nitrate, is considerably less than in pure water, and further, that the diminution caused by equivalent amounts of the two salts is quite different. We will now compare quantitatively the experimental results with the requirements of the principle of solubility effect.

The laws of mass action require that in the case of a saturated solution of a tri-ionic salt, the product of the concentration of the bivalent ion into the square of the concentration of the monovalent ion shall be a constant quantity, whatever other salts may be present at the same time.[1] In this case the equation

$$Pb \times (I)^2 = \text{a constant}$$

should hold, where the chemical symbols denote the concentrations of the respective ions.

If m_0 is the solubility of lead iodide in pure water, m its solubility in a solution of potassium iodide or lead nitrate whose concentration is n (all expressed in equivalents), and a_0, a, and a_1, the corresponding dissociation-values, the following equation applies in the case where lead nitrate is present:

$$(ma + na_1)\, m^2a^2 = m_0{}^3a_0{}^3$$

and where potassium iodide is present:

$$ma\,(ma + na_1)^2 = m_0{}^3a_0{}^3.$$

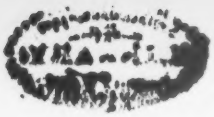
[1] Ztschr. phys. Chem., 9, 627.

The value m_0a_0, the concentration of the ions in the saturated solution in pure water, is found to be 0.002873; and the values of na_1, the concentrations of the ions in the solutions of lead nitrate and potassium iodide in the four solubility experiments are given in the first and fourth columns of the last table. From these we have calculated the values of *ma* (the concentration of the lead iodide ions), by the two formulæ given above.

This cubic equation is easily solved by substituting an estimated value of *ma*, and calculating the value of the left member of the equations, repeating this process until the value thus found becomes equal to $m_0^3a_0^3$. The theoretical values obtained in this way are found in the last table under the headings "calculated."

The agreement between the experimental and the theoretical values, although not complete, is, however, entirely sufficient to prove the essential correctness of the solubility principle. The deviations are in the case of the lead nitrate 0.9 and 0.3 per cent., and in that of the potassium iodide 4.1 and 2.2 per cent. It is to be considered, however, that the values of *ma* were not directly measured, but were obtained as the differences of two larger experimentally determined values, whereby the percentage error is greatly increased.

In order to give an idea of the existing error-relations, it may be mentioned that an error of half of one per cent. in the conductivity of the solution of lead nitrate saturated with lead iodide, and an equal error in the subtracted conductivity of the pure solution of lead nitrate, would cause in the value *ma* an error which would probably amount to 1.3 per cent. in the 0.003077 normal solution, and 0.9 per cent. in the 0.002000 normal solution. Equal errors in the experiments with potassium iodide would cause errors of 2.0 and 1.0 per cent., respectively, in *ma*. It is, therefore, seen that the method cannot furnish very accurate results, and it is not improbable that the differences between the actual and the calculated values are due to experimental errors.

It has, therefore, been established by this investigation within the somewhat wide limits of experimental error, that *the solubility of lead iodide is diminished both by potassium iodide and by lead nitrate, in such a way that the product of the concentration of the lead ions into the square of the concentration of the iodine ions remains constant.*

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
January, 1898.